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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXXX.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. xliv., p. 28, line 4, *for* "$\frac{0\cdot0765}{5\cdot2} = 68$" *read* "$\frac{5\cdot2}{0\cdot0765} = 68$."

" " p. 33, " 5, *for* "3,696" *read* "36,960."

" lxxix., p. 243, column 2, line 19, *for* "Flower" *read* "Fowler."

" " p. 362, line 15, *for* "J. Murray Browne" *read* "T. Murray Browne."

" " " last line, *for* "Wokley" *read* "Cookley."

" " p. 364, line 13 from bottom, *for* "Coal and Iron Trades Review" *read* "American Engineer."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1884–85.—PART II.

Sect. I.—MINUTES OF PROCEEDINGS.

13 January, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Members have been transferred to the class of

Members.

Alfred Edward Carey.
Robert Edward Creswell.
Killingworth William Hedges.
James Ormsby Lawder.
James Young.

The following Candidates have been admitted as

Students.

George Charles Badham.
Percy Munro Beaumont.
James Lombard Becher De la Cour.
Vernon Warburton Delves-Broughton.
Alfred Eastwood.
Thomas William Franks.
Norman Walter John Gibson.
Godfrey Philip Heisch.
Henry Golding Joy.
James Lee.
Bell George Lloyd.
Charles Vereker Lloyd.
Philip Glynn Messent.
Harry Arthur Nock.
Joseph Spiers Pickering.
Frank Edward Priest.
Herbert Peter Barrow Rigby.
John Arthur Thornton.
Henry Armstrong Westmacott.
Harry Wreathall.

The following Candidates have been balloted for and duly elected as

Members.

Peter Duckworth Bennett.
Thomas Alfred English.
Thomas Hindmarsh.
Walter Charleton Hughes.
John Rochfort.

Associate Members.

David Bonar.
Peter Dunn.
Lewis Frederick Evelegh.
Stephen Henderson, Stud. Inst. C.E.
Edward Henshall.
George William Hersey.
Edward Hopkinson, M.A., D.Sc.
Gisbert Kapp.
Hugh Frederick Perkins, Stud. Inst. C.E.
Percy Rickard, Stud. Inst. C.E.
Stuart Arthur Russell, Stud. Inst. C.E.
Charles Walter Smith.
Henry John Spooner.
Harry Townsend.
Francis Wiswall.

Associates.

Henry Card.
James Rock.
Harry Borlase Willock, Capt. R.E.

Sir Frederick J. Bramwell addressed the Meeting in the following terms on taking the Chair, for the first time, after his election as President:—

Gentlemen—

Born in the year this Institution was founded, and by God's mercy permitted to continue an active worker for more than half a century, I now find myself, through your favour, elected to the Presidency.

In accordance with established usage I have the privilege, but also, I regret to say, the heavy burden, of delivering an address; a privilege, because by your courtesy I see around me an audience of most distinguished men; a heavy burden, because of my inability to make an address worthy of that audience.

I can imagine, that in many Societies, each President, as he takes office, must find an increase, in the difficulty of selecting a subject for his address. He must feel that the area to which he is restricted, has been so well trodden by his predecessors, that it is hardly possible for him to strike out a new path on untraversed ground; but it seems to me that many years must elapse, (indeed I doubt if the time will ever come), before the President of the Institution of Civil Engineers need fear such a condition of things. Our profession is so widespread, it ramifies in so many directions, that successive Presidents can not be embarrassed for want of a subject, but rather, must find a difficulty in making a selection among many subjects.

I have been determined in my choice, by the consideration that our Honorary Member, His Royal Highness the Prince of Wales, has seen fit to honour the Institution by appointing its President

chairman of the Executive Council of that Exhibition of Inventions, which is shortly to be held at South Kensington. I have thought it would be fitting and appropriate, therefore, that in my double capacity of your President and of Chairman of that Council, I should direct attention this evening to some of the matters which will be, or which ought to be, contributed to the Exhibition.

The Exhibition will consist of two divisions very dissimilar in their nature, the one "Inventions" and the other "Music." Division I. (Inventions) is separated into thirty-one groups, and these groups into one hundred and sixty-five classes, but to a few of these only will reference be made. In fact, I must restrict myself, to such matters as are more particularly connected with civil engineering, which as defined by our charter, may be summarized as comprising "all engineering other than military." I must, indeed, make a still further limitation; as engineering, regarded in this sense, is so comprehensive in its scope, that it is difficult to say, what there is of invention, in which the engineer has not an interest. Even a purely chemical invention may not be foreign to our consideration; take, as a test of this, an invention relating to the manufacture of gas, or to the purification of water, or to the treatment of metals, or to some kindred subject.

I propose, therefore, to devote the very limited time at my disposal, to the consideration of some of the most important of those improvements, which are obviously, and immediately connected with civil engineering.

I am aware of the danger there is of making a serious mistake, when one excludes any matter, which at the moment appears to be of but a trivial character. For, who knows how speedily some development may show that the judgment which had determined the rejection was entirely erroneous, and that the invention which had been passed over, was in truth the germ of a great improvement.

Nevertheless, in the interests of time some risk must be run, and a selection must be made; I propose, therefore, to ask your attention while I consider certain of (following the full title of Division I.) "The Apparatus, Appliances, Processes and Products, invented or brought into use since 1862."

In those matters which may be said to involve the principles of engineering construction, there must of necessity be but little progress to note. Principles are generally very soon determined, and progress ensues, not by additions thereto, but by improvement in the methods of giving to those principles a practical shape, or by combining in one structure, principles of construction

which had been hitherto used apart. Therefore to avoid the necessity of having to pause, in referring to a work, by finding that the boundary of principle is being overstepped, and the domain of construction is being invaded, I think it will be well to treat these two heads together.

If my record had gone back to just before 1851 (the date of the Great Exhibition), I might have described much progress in the principles of girder-construction; for shortly prior to that date, the plain cast-iron beam, with the greater part of the metal in the web, and with but little in the top and bottom flange, was in common use; and even in the preparation of the building for that Exhibition, it is recorded, that one of the engineers connected therewith had great difficulty in understanding, how it was that the form of openwork girder, with double diagonals introduced therein (a form, which was for years afterwards known as the Exhibition girder) was any stronger than a girder with open panels separated by uprights, and without any diagonals. But, long before 1862, the Warren and other truss-girders had come into use, and I am inclined to say, that so far as novelty in the principle of girder-construction is concerned, I must confine myself to that combination of principles, which is represented by the suspended cantilever, of which the Forth Bridge of Messrs. Fowler and Baker [1] only now in course of construction, affords the most notable instance. It is difficult to see how a rigid bridge, with 1700 feet spans, and with the necessity for so great a width of clear headway below, could have been constructed, without the application of this principle.

Pursuing this subject of bridge-work. The St. Louis Bridge of Mr. Eads may, I think, be fairly said to embody a principle of construction, novel since 1862, that of employing for the arch-ribs, tubes composed of steel staves hooped together.

Further, in suspension bridges there has been introduced, that which I think is fairly entitled to rank among principles of construction, the light upper chain, from which are suspended the linked truss-rods, doing the actual work of supporting the load, these rods being thus maintained in straight lines, and without the flexure at the joints, due to their weight. In the East River Bridge, New York, there was also introduced, that which I believe was a novelty in the mode of applying the wire cables. These were not made as untwisted cables, and then hoisted into place, thereby imposing severe strains upon many of the wires composing

[1] "Engineer," vol. lviii., p. 357.

the cable, through their flexure over the saddles and elsewhere, but the individual wires were led over from side to side, each one having the length appropriate to its position, and all therefore, when the bridge was erected, having the same initial strain and the same fair play.

Within the period we are considering, the employment of testing-machines has come into the daily practice of the engineer; by the use of these he is made experimentally acquainted with the various physical properties of the materials he employs, and is also enabled in the largest of these machines to test the strength and usefulness of these materials, when assembled into forms, to resist strain, as columns or as girders. I of course do not for one moment mean to say that experimental machines, were unknown or unused, prior to 1862—chain cable testing-machines are of old date, and were employed by our Past-President, Mr. Barlow, and by others, in their early experiments upon steel—but I speak of it as a matter of congratulation, that in lieu of such machines being used, by the few, and at rare intervals upon small specimens, for experimental purposes, they are now employed in daily practice and on a large scale.

In harbour-work, we have had the principle of construction, employed by Mr. Stoney at Dublin,[1] where cement concrete is moulded into the form of the wall, for its whole height and thickness, and for such a length forward as can be admitted, having regard to the practical limit of the weight of the block, and then, the block being carried to its place, is lowered on to the bottom which has been prepared to receive it, and is secured to the work already executed by groove and tongue.

It would not be right, even in this brief notice of such a mode of construction, to omit mention of the very carefully thought out apparatus, by which the blocks are raised off the seats whereon they have been made, and are transported to their destination. It is no simple undertaking (even in these days) to raise (otherwise than hydraulically), a weight of 350 tons, which is the weight of the blocks with which Mr. Stoney deals. But he does this, by means of pulley-blocks attached to shears built on the vessel which is to transport the block, and he contrives to lift the weight without putting upon his chains, the extra strain due to the friction of the numerous pulleys over which they pass. The height of the lift is only the few inches, needed to raise the block clear of the quay, on which it has been formed, and this is

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 332.

obtained, by winding up the chain by steam gear quite taut so as to take a considerable strain, but not that equal to the weight of the block, and then water is pumped into the end of the vessel opposite to that upon which the shears are carried, this latter end rises, and the block is raised off the seat, on which it was formed, without the chains being put to work to do the actual lifting at all. The vessel, with the block suspended to the shear legs and over the bows, is then ready to be removed to the place where the wall is being built.

A word must here be said about an extremely ingenious mode of dealing with the slack chain, to prevent its becoming fouled, and thus not paying out properly, when the block is being lowered. This is accomplished by reeving the slack of the chain over two fixed sets of multiple sheaves. A donkey-engine works a little crab having a large drum, the chain from which is connected with the main chain, and draws it round the multiple sheaves, so as to take up the slack as fast as the main crab gives it out. The steam is always on the donkey, which is of such limited dimensions that it can do no injury to the chain even when its full power is in vain endeavouring to draw it any further; directly, however, the main crab gives more slack, and the chain between it and the two sets of sheaves falls into a deeper catenary, and one which therefore puts less opposition to the motion of the donkey-engine, that engine goes to work and makes a further haul upon the slack, and in this way, and automatically the slack is kept clear.

A noteworthy instance of the use of pneumatic appliances, in cylinder-sinking for foundations, is that in progress at the Forth Bridge. The wrought-iron cylinders are 70 feet in diameter at the cutting edge, and have a taper of about 1 in 46. They are, however, at a height of 1 foot above low water (that is at the commencement of the masonry work of the pier) reduced to 60 feet in diameter; at their bottoms there is a roofed chamber, into which the air is pumped, and in which the men work when excavating; this roof being supported by ample main and cross lattice girders. Shafts with air-locks and pipes for admitting water and for ejecting silt are provided. The air-locks are fitted with sliding doors, worked by hydraulic rams, or by hand, the doors being interlocked in a manner similar to that in which railway points and signals are interlocked, so that one door cannot be opened until the other is closed. The hoisting of the excavated material is done by a steam engine fixed outside the lock, and working a shaft on which there is a drum inside the lock, the shaft passing air-tight through a stuffing box. A

separate air-lock with doors, ladder, &c., complete, is provided to give ingress and egress for the workmen.

I have already adverted to one Scotch bridge; I now have to mention another, viz., the Tay Bridge, also in course of construction. Here the cylinders are sunk, while being guided, through wrought-iron pontoons, which are floated to their berths and are then secured at the desired spot by the protrusion, hydraulically, of four legs, which bear upon the bottom, and thus, until they are withdrawn, convert the pontoon from a floating, into a fixed structure.

I regret that time will not admit of my giving any description of the modes of "cut and cover," which have been proposed, for the performance of sub-aqueous works, sometimes the proposition has been to do this by means of cofferdams, and with the work therefore open to the daylight during execution, and sometimes by movable pneumatic appliances.

Consideration of sub-aqueous works necessarily leads the mind to appliances for diving, and although its date is considerably anterior to 1862, I feel tempted, as I believe the construction is known to very few of our members, to say a few words about the diving apparatus known as the "Bateau-plongeur," and used at the "barrage" on the Nile. This consists of a barge fitted with an air-tight cabin, provided with an air-lock, and having in the centre of its floor, a large oval opening, surrounded by a casing standing up above the water-line. In this casing, another casing slides telescopically, the upper part of which is connected to the top of the fixed casing by a leather "sleeve." When it is desired to examine the bed of the river, the telescopic tube is lowered till it touches the bottom, and then, air is pumped into the cabin, until the pressure is sufficient to drive out the water, and thus to expose the bottom. This appears to be a very convenient arrangement for shallow draughts of water. Reverting for a moment to Mr. Stoney's work, I may mention, that he uses for the greater depths he has to deal with, when preparing the bed to receive his blocks, a diving apparatus which, (while easily accessible at all times) dispenses with the necessity of raising and lowering, needed in an ordinary diving-bell, to allow of the entrance and exit of the workmen. This is effected by mounting a hollow cylinder on a bell of adequate dimensions; the cylinder being furnished at its top with an air-lock, by which access can be obtained to the bell while it remains submerged.

Beyond the general improvement in detail, and in the mode of manufacture, and with the exception of the application of the

telephone, there is probably not much to be said, in the way of invention, or progress, in connection with the ordinary dress of the diver. But one great step has been made in the divers' art by the invention of Mr. Fleuss. He has succeeded in devising a perfectly portable apparatus, containing a chemical filter, by means of which the exhaled breath of the diver is deprived of its carbonic acid; the diver also carries a supply of compressed oxygen from which to add to the nitrogen remaining after filtration, a supply of oxygen, in substitution for that which has been burnt up in the process of respiration. Armed with this apparatus, a diver is enabled to follow his vocation without any air-tube connecting with the surface, indeed without any connection whatever. A notable instance, of a most courageous use of this apparatus, was afforded by a diver named Lambert, who, during one of the inundations which occurred in the construction of the Severn tunnel, descended into the heading, and proceeding along it for about 330 yards, (with the water standing some 35 feet above him,) closed a sluice door, through which the water was entering the excavations, and thus enabled the pumps to unwater the tunnel. On this occasion, Lambert was under the water, and without any communication with those above, for one hour and twenty-five minutes.[1] The apparatus has also proved to be of great utility in cases of explosion in collieries, enabling the wearer to safely penetrate the workings, even when they have been filled with the fatal choke damp, to rescue the injured or to remove the dead.

With respect to the subject of tunnelling thus incidentally introduced—in sub-aqueous work of this kind, I have already alluded to that which is done by "cut and cover," but where the influx of water is a source of great difficulty, as it was in the old Thames tunnel, (though in this case for water one should read silt or mud), I do not know that anything has been devised so ingenious as the "shield" there employed; improvement has however been made by the application of compressed air. In the instance of the Hudson River tunnel,[2] the work was done in the manner proposed, so long ago as the year 1830, by Lord Cochrane (Earl Dundonald); the arrangement is fully described in that specification of his, No. 6018, wherein he discloses, not merely the crude idea, but the very details, needed for compressed-air cylinder-sinking and tunnelling, including air-locks and hydraulically-

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[1] "The Engineer," vol. lviii., p. 232.

[2] Transactions of the American Society of Civil Engineers, vol. ix., p. 259.

sealed modes, for the introduction and extraction of materials. I may perhaps be permitted to mention that some few years ago I devised for a tunnel through the water-bearing chalk, a mode of excavation, by the use of compressed air to hold back the water, combined with the employment of a tunnelling machine. This work, I regret to say, was not carried out.

But there are, happily, cases of sub-aqueous tunnelling where the water can be dealt with by ordinary pumping power, more or less extensive, and where the material is capable of being cut by a tunnelling machine. This was so in the Mersey tunnel, and would be in the Channel tunnel.

In the Mersey tunnel, and in the experimental work of the Channel tunnel, Colonel Beaumont and Major English's tunnelling-machine has done most admirable work. In the 7-feet-4-inch diameter heading, in the new red sandstone of the Mersey tunnel, a speed of as much as 10 yards forwards in twenty-four hours has been averaged, while a maximum of over 14 yards has been attained; while in the 7-feet heading for the Channel tunnel, in the grey chalk, a maximum speed of as much as 24 yards forwards in the twenty-four hours has been reached on the English side, and with the later machine put to work at the French end, a maximum speed of as much as 27½ yards forwards in the twenty-four hours has been effected.

In ordinary land tunnelling, since 1862, there has been great progress, by the substitution of dynamite, and preparations of a similar nature for gunpowder, and by the improvements in the rock-drills worked by compressed air, which are used in making the holes into which the explosive is charged.

For boring for water, and for many other purposes, the diamond drill has proved of great service, and most certainly its extended use should be welcomed by the geologist, as it admits of specimens of the stratum passed through being taken in the natural unbroken condition more readily than by other modes; these specimens showing not only the material and the very structure of the rock, but the direction and the angle of the dip of the beds.

Closely connected with tunnelling machines are the machines for "getting" coal. This "getting," when practised by manual labour, involves, as we know, the conversion into fragments and dust, of a very considerable portion of the underside of the seam of coal, the workman labouring in a confined position, and in peril of the block of coal breaking away and crushing him beneath it. Coal-getting machines, such as those of Mr. Firth, worked by compressed air, reduce to a minimum the waste of coal, relieve the

workman of a most fatiguing labour in a constrained position, and save him from the danger to which he is exposed in the hand operation. That the commercial failure of these machines should be due to the opposition of the colliers is a matter of deep regret; it is to be deplored on many grounds; but especially as showing how little the true principles of political economy are understood by men, who are commonly well-informed on many other points.

In connection with colliery work, and indeed in connection with explosives, in the sense of a substitution for them of sources of expansion acting more slowly, mention should be made of the hydraulic wedge. The employment of these in lieu of gunpowder, to force down the block of coal that had been undercut, is one of the means to be looked to for diminishing accidents in collieries.

Another substitute for gunpowder is found in the utilization, of the expansion of lime when wetted. This has given birth to the lime cartridge, the merits of which are now fully recognized, but it is feared that in this case also trade prejudices may prevent its introduction.

While on this subject of Accidents in Mines, it will be well to call attention, to the investigations that have been made into the causes of these disasters, and into the part probably played by the minute dust which prevails to so great an extent in dry collieries. The experiments of our Honorary Member, Sir Frederick Abel, on this point have been of the most striking and conclusive character, and have corroborated the investigations of the late Macquorn Rankine into the origin of explosions in flour-mills and in rice-mills, which had previously been so obscure. The name of Mr. Galloway should also be mentioned, as one of the earliest workers in this direction.

At first sight, pile-driving appears to have but little connection with explosives, but it will be well to notice an invention which has been brought into practical use (although not largely, in this country at all events) for driving piles, by allowing the monkey to fall on a cartridge placed in a cavity in the cap on top of the pile; the cartridge is exploded by the fall, and in the act of explosion drives down the pile and raises the monkey; during its ascent and before the completion of its descent, time is found for the removal of the empty cartridge, and the insertion of a full one.

In the days of Brindley and of Smeaton, and of the other fathers of our profession, whose portraits are on these walls, canals and canalized rivers formed the only mode of internal transit which

was less costly than horse-traction, and, thanks to their labours, the country has been very well provided with canals; but the introduction of railways proved, in the first instance, a practical bar to the extension of the canal system, and eventually, a too successful competitor with the canals already made. Frequently the route that had been selected by the canal engineer was found (as was to be expected) a favourable one for the competing railway, and the result was, the towns that had been served by the canal, were served by the railway, which was thus in a position to take away, even the local traffic of the canal. For some time it appeared as though canal undertakings and canalized river navigations must fail, for although heavy goods could be carried very cheaply on canals, and although in the case of the many works and factories erected on their banks, or on basins connected with them, there was (with canal navigation) no item of expense corresponding to the cost of cartage to the railway stations, yet the smallness of the railway rates for heavy goods, and the greater speed of transit were found to be more than countervailing advantages.

But when private individuals have embarked their capital in an undertaking, they do not calmly see that capital made unproductive, nor do they refrain from efforts to preserve their dividends. Canal-companies therefore set themselves to work, to add to their position of mere owners of water highways, entitled to take toll for the use of those highways, the function of common carriers, thus putting themselves on a par with the railway companies, who, as no doubt is within the recollection of our older members, were in the outset legalised only as mere owners of iron highways, and as the receivers of toll from any persons who might choose to run engines and trains thereon—a condition of things which was altered, as soon as it was pointed out, that it was utterly incompatible, either with punctuality, or with safe working. This addition to the legal powers of the canal companies made by the Acts of 1845 and 1847, has had a very beneficial effect upon the value of their property, and has assisted to preserve a mode of transport competing with that afforded by the railways. Further, the canal proprietors have from time to time endeavoured to improve the rate of transport, and with this object have introduced steam- in lieu of horse-haulage, and by structural improvements have diminished the number of lockages.

Many years before the period we are considering, there was employed, to save time in the lockages and to economise water, the system of inclined planes, where the barges were transferred

from one level to another, either water-borne, in a travelling caisson, as on the Monklands incline,[1] or supported on a cradle as in the incline on the Morris canal, in the state of New Jersey;[2] but an important improvement, on either of these modes of overcoming a great difference of level is the application of direct vertically-lifting hydraulic power. A notable instance of this system was brought before the Institution in a Paper read on the "Hydraulic Canal Lift at Anderton, on the River Weaver," by S. Duer,[3] and another instance exists on the Canal de Neufossé, at Fontinettes, in France, the engineers being Messrs. Clark and Standfield, who have other lifts in progress. This system reduces, the consumption of water, and the expenditure of time to a minimum.

With respect to canalised rivers; the difficulty that must always have existed when these rivers, (as was mostly the case) were provided with weirs to dam up the water for giving power to mills, has been augmented, of late years by the change in the character of floods. It has frequently been suggested that in these days of steam-motors in lieu of water-power, and of railways in lieu of water-carriage, the injury done by obstructing the delivery of floods, is by no means compensated by the otherwise all but costless power obtained, or by the preservation of a mode of transport competing with railways. It has thereupon been suggested that it would be in the interests of the community, to purchase and extinguish both the manufacturing- and the navigation-rights, so as to enable the weirs to be removed, and free course to be provided for floods. It need hardly be said however that if means could be devised for giving full effect to the river-channels for flood-purposes, while maintaining them for the provision of motive power and for navigation, it is desirable that this should be done. The employment of readily, or it may be, of automatically, movable weirs appears to offer the solution to this problem.

Two very interesting Papers on the subject by Messrs. Vernon-Harcourt and R. B. Buckley were read and discussed in the session 1879–1880.[4] These dealt, I fear exclusively, with foreign, notably with French and Indian examples. I say I fear, not in the way of imputing blame to the Authors for not having noticed English weirs, but because, the absence of such notice, amounts to

[1] Minutes of Proceedings Inst. C.E., vol. xiii., p. 205.
[2] *Ibid.*, vol. xiii., pp. 206 and 212.
[3] *Ibid.*, vol. xlv., p. 107.
[4] *Ibid.*, vol. lx., pp. 24, 43.

a confession of backwardness in the adoption of remedial measures on English rivers. An instance, however, of improvement since then, has been the construction by Mr. Wiswall, the engineer to the Bridgewater Navigation Co. (on the Mersey and Irwell section of that navigation), of the movable Throstle Nest weir at Manchester. I think there is good reason to believe that by the adoption of movable weirs, rivers in ordinary times may be dammed up to retain sufficient water to admit of a paying navigation, and sufficient water for the mills on their banks, while in times of flood they shall allow channels as efficient for relief, as if every weir had been swept away.

But the great feature of late years, in canal engineering, is not the preservation, or improvement, of the ordinary internal canal, but the provision of canals, such as the completed Suez canal, the Panama canal in course of construction, the contemplated Isthmus of Corinth canal—all for saving circuitous journeys in passing from one sea to another—or in the case nearer home of the Manchester Ship canal, for taking ocean steamers many miles inland.

But the old fight between the canal engineer and the railway engineer, or, more properly speaking, between the engineer when he has his canal " stop " on, and the same individual when he has his railway " stop " on (you will see that I am borrowing a figure, either from "Dombey and Son," where Mr. Feeder, B.A., is shown to us with his Herodotus " stop " on; or, as is more likely, I am thinking of the organs to be exhibited in the Second Division "Music" of that Exhibition of which I have the honour to be Chairman)—I am afraid this is a long parenthesis breaking the continuity of my observations, which related to the old rivalry between canal and railway engineering—I was about to say, that this rivalry was revived, even in the case of the transporting of ocean vessels from sea to sea, for we know that our distinguished Member, Mr. Eads, is proposing to connect the Atlantic and the Pacific Oceans, by means of a ship-railway. He suggests that the largest vessels should be raised out of the water, in the manner commonly employed in floating-docks, and should then be transferred to a truck-like cradle on wheels, fitted with hydraulic bearing-blocks, (this being, however, not a new proposition as applied to graving docks) so as to obtain practical equality of support for the ship, notwithstanding slight irregularities in the roadway, while he proposes to deal with the question of changes of direction, by the avoidance of curves and by the substitution of angles, having, at the point of junction of the two sides, turntables on which the cradle and

ship will be drawn, and that can be moved with perfect ease, notwithstanding the heavy load, because they will be floating in water, contained in circular tanks forming the curbs for the turntables.

The question of preserving the level of the turntable, whether unloaded, partially loaded, or loaded, is happily met by an arrangement of water ballast and of pumping.

I cannot pass away from the mention of Mr. Eads' work, without just reminding you of the successful manner in which he has dealt with the mouth of the Mississippi, by which he has caused that river to scour and maintain a channel thirty feet deep at low water, instead of that of eight feet deep, which prevailed there before his skilful treatment.

Neither can I refrain from mentioning the successful labours of our friend Sir Charles Hartley, in improving the navigation of that great European river, the Danube.[1] I am sure we are all rejoiced to see that one of the lectures of the forthcoming series, that on "Inland Navigation," is to be delivered by him, and I do earnestly trust, he will remember, it is his duty to the Institution, not to leave important and successful works un-referred to, because those works are his own.

I regret that time does not admit of my noticing the many improved machines for excavating, to be used either below water or on dry land.

I also regret, for similar reasons, I must omit all mention of ship-construction, whether for the purposes of commerce or of war, a subject that would naturally follow that of rivers, and of ship-railways and canals, and would have enabled me to speak of the great debt this branch of civil engineering, owes to the labours of our late Member, William Froude. It would have enabled me also to deal with the question of material for ships, and with the question of armour-plating, in which, and in the construction of ordnance, our past President Mr. Barlow and myself, as the two Lay Members of the Ordnance Committee, are so specially interested.

The mention of armour-plates, inevitably brings to our minds the consideration of ordnance, but I do not intend to say even a few words on this head of invention and improvement—a topic to which a whole evening might well be devoted—because only three years ago my talented predecessor in this chair, Sir William Armstrong, made it the subject of his inaugural address, and dealt with it in so masterly and exhaustive a style, as to render it

[1] Minutes of Proceedings Inst. C.E., vol. xxi., p. 277; vol. xxxvi., p. 201.

absolutely impossible for me, to usefully add anything to his remarks.

I cannot, however, leave this branch of the subject without mentioning, not a piece of ordnance, but a small-arm, invented since the date of Sir William's address. I mean the Maxim machine-gun.[1] This is not only one of the latest, but is certainly one of the most ingenious pieces of mechanism that has been devised. The single-barrel fires the Martini-Henry ammunition; the cartridges are placed in loops upon a belt, and when this belt is introduced to the gun, and some five or six cartridges have been drawn in, by as many reciprocations of a handle, the gun is ready to commence firing. After the first shot, which must be fired by the pulling of a trigger in the ordinary way, the gun will automatically continue to send out shot after shot, until the whole of the cartridges on the belt are exhausted; and if care is taken before this happens, to link on to the tail of the first belt, the head of a second one, and another belt to this, and so on, the firing will be automatically continuous, and at a rate, anywhere between one shot per minute and six hundred shots per minute, dependent on the will of the person in charge of the gun, the whole of the operations of loading, firing, and ejecting the cartridge being performed by the energy of the recoil. This perfectly automatic action, enables the man who works the gun, to devote his whole attention to directing it, and as it is constructed to be trained in any direction, and to be elevated and depressed, whilst the gun is firing, he can aim the stream of bullets to any point he may choose. In the absence of proper and long-continued trials, I must not be understood as expressing any opinion how far this weapon may fulfil the functions demanded of a machine-gun in actual warfare, but whatever may be the eventual verdict upon this all-important point, I desire to record my opinion that this is one of the most ingenious pieces of mechanism I have ever inspected.

Since 1862 the power of defending sea-ports has been added to, by the application of submarine mines, arranged to be fired by impact alone, or to be fired on impact when (under electrical control) the firing arrangement is set for the purpose, or to be fired electrically from the shore by two persons stationed on cross-bearings, both of whom must concur in the act of explosion. These mines are charged with gun-cotton, the development of which owes so much to Sir Frederick Abel, while for purposes of

[1] "Engineering," vol. xxxviii., p. 431.

attack, the same material, not yet in practical use for shells, is adopted as the charge for torpedoes, which are either affixed to a spar or are carried in the head of a submerged cigar-shaped body. By a compressed air, or by a direct steam impulse arrangement, these weapons are started on their course, and then the running is taken up by their own engines operating on screw-propellers, driven by a magazine of compressed air contained in the body of the torpedo. Means are also provided to maintain the desired level below the water surface. The torpedo may either be projected from the war-ship itself or from one of those launches which owe their origin to our member Mr. John Isaac Thornycroft, who first demonstrated the feasibility of that which was previously considered to be impossible, viz., the obtaining a speed of 20 miles an hour, and over, from a vessel not more than 80 feet long. Experiments have been carried on in the United States by Captain Ericsson, to dispense with the internal machinery of the torpedo, and to rely for its traverse, through the water, upon the original impulse given to it by a breech-loading gun, carried, at the requisite depth below the water-level, in a torpedo boat. This gun, having a feeble charge of powder at a low gravimetric density, fires the torpedo, and it is said, succeeds in sending it many yards, and with a sufficient terminal velocity to explode the charge by impact. Also, in the United States, experiments have been made with a compressed air-gun of 40 feet in length, and 4 inches in diameter, (probably by this time replaced by a gun of 8 inches in diameter), to propel a dart through the air, in the front end of which dart, there is a metallic chamber containing dynamite.

Although no doubt the best engineer is the man who does good work with bad materials, yet I presume we should not recommend any member of our profession, to select unsuitable materials, with the object of showing how skilfully he can employ them. On the contrary, an engineer shows his ability by the choice of those materials which are the very best for his purpose, having regard, however, to the relative facilities of carriage, to the power of supply in sufficiently large quantities, to the ease with which they can be worked up, or built in, and to their cost.

Probably few materials have been found more generally useful to the civil engineer, in works which are not of metal, than has been Portland cement. It should be noticed that during the last twenty-two years, great improvements have been made in the grinding and in the quality of the cement. These have been largely

due to the labours in England of our Member, Mr. John Grant,[1] to the labours of foreign engineers, and to the zeal and intelligence with which the manufacturers have followed up the question, from a scientific as well as from a practical point of view, not resting until they were able with certainty, to produce a cement such as the engineer needed.

I do not know that there is very much to be said in the way of progress, (so far as the finished results are concerned,) in the materials which Portland cement, and other mortars are intended to unite. Clean gravel and ballast, and clean sand, are, I presume, very much the same in the year 1885, as they were not only in the year 1862, but as they were in the year 1. The same remark applies to stone and to all other natural building materials; and, indeed, even the artificial material, brick, cannot in these days be said to surpass in quality, the bricks used by the Romans, in this island nineteen hundred years ago, but as regards the mode of manufacture, and the materials employed, there is progress to be noted. The brick-making machine, and the Hoffmann kiln, have economised labour and fuel, while attempts have been made, which I trust may prove successful, for utilizing the clay, which is to be found, in those enormous mounds of slate waste, which disfigure the landscape in the neighbourhood of slate quarries. Certain artificial stones, moreover, appear at last to be produced with satisfactory uniformity and powers of endurance, so as to compare favourably with the best natural stone in respect of these qualities, and having the advantage also that the pieces can be at once made of the finished dimensions and shape, thus being ready for use, without labour of preparation.

Reverting to natural materials, there remains to be mentioned that great class, timber. In new countries the engineer is commonly glad to avail himself of this material, to an extent which among us is unknown. For here, day by day, owing to the ready adaptability of metals to the uses of the engineer, the employment of wood is decreasing. Far, indeed, are we from the practice of not more than a hundred years ago, when it was thought proper, to make the shell of a steam-engine boiler of wooden staves. The engineer of to-day, in a country like England, refrains from using wood. He can't cast it into form; he can't weld it. Glue, (even if marine,) would hardly be looked upon as an efficient substitute for a sound weld; and the fact is, that it is practically im-

[1] Minutes of Proceedings Inst. C.E., vol. xxv., p. 66, and vol. xxxii., p. 266, and vol. lxii., p. 98.

possible to lay hold of timber when employed for tensile purposes, so as to obtain anything approaching to the full tensile strength. If it be desired to utilize metals for such a purpose, they can be swollen out into appropriate "eyes" to receive the needed connection; but this cannot be done with wood, for the only way of making an enlarged eye in wood, is by taking a piece that is big enough to form the eye, and then cutting away the superfluous portion of the body. Moreover, when too much exposed to the weather, and when too much covered up, wood has an evil habit of rotting, compared with the rapidity of which mode of decay, the oxidising of metals is unimportant. Further, one's daily experience of the way in which a housemaid prepares a fire for lighting, is suggestive of the undesirability, of the introduction of resinous sticks of timber, even although they may be large sticks, into our buildings.

Many attempts, as we know, have been made to render timber proof against these two great defects of rapid decay and of ready combustibility, and, as it appears to me, it is in these directions alone one can look for progress in connection with timber. With respect to the first, it was only at the last meeting of the Institution we presented a Telford medal and a Telford premium, to Mr. S. B. Boulton for his Paper "On the Antiseptic treatment of Timber,"[1] to which I desire to refer all those who seek information on this point.

With respect to the preservation from fire of inflammable building materials, the processes, more or less successful, that have been tried are so numerous, that I cannot even pretend to enumerate them. I will, however, just mention one, the Asbestos paint, because it is used to coat the wooden structures of the Inventions Exhibition. I think it is not too much to say that those buildings would have been consumed by a fire that broke out in an exhibitor's stand during last year's dry summer, had they not been painted with this paint. The fire destroyed every object on the stand, but happily did not set the painted wood-work on fire, although it was charred below the surface. I do not pretend to say, that a surface application, can enable wood to resist the effects of a continued exposure to fire, but it does appear that it can prevent its ready ignition.

Leaving the old-world materials of stone and wood, let us come, not only to the Bronze age, but to the Iron age, and direct our attention during a few minutes, to the improvements which, in

[1] Minutes of Proceedings Inst. C.E., vol. lxxvii., p. 97.

twenty-two years, have been made—and first to deal with that form of "iron" known as "steel." I am aware that I am laying myself open to a charge of having committed a most tremendous "bull," but I am prepared to defend my form of speech, on the very strong ground, that no one can say, speaking as a metallurgical chemist, where the dividing line is, between commercial iron and commercial steel, for it is quite certain there is material, which would be currently bought and sold, and used as steel, which is more near to pure iron, than is other material, which would be commercially bought and sold, and used as iron. It is now nearly eight years since I delivered, at the Royal Institution, a lecture on "The Future of Steel,"[1] and every year that has passed, has justified the opinions I then ventured to put forward, as to the way in which steel, made by fusion, would supersede iron made by the puddling process; and I am not afraid to repeat my prophecy, that the time will come, when the use of iron made by that process, will be restricted to the manufacture of the small articles produced by the hand labour of the village blacksmith, for whose art, its plastic character, and ready power of welding, eminently fit it.

Probably the first great revelation in steel manufacture was the exhibition of the ingots, with other products shown by "Krupp" in the '51 Exhibition; it soon became known, however, that these exhibits gave us after all no further information than this: viz., that it did not follow because the limit of the charge of a crucible might be 50 or 60 lbs. the limit of the size of the ingot must also be 50 or 60 lbs.; in fact the world was shown, that more than one pot of steel might be discharged into the same ingot-mould; indeed, that hundreds of pots might be. Do not imagine for one moment I am depreciating this step. It was an enormous one, at the time when the production of fused steel, involved the employment of the crucible. But, according to my judgment, the making of steel in crucibles is not so satisfactory a mode of obtaining uniformity in large masses, as is either of the two other great systems of manufacture, I mean the Bessemer and the Siemens; the processes which have changed the whole complexion of the iron industry. For years after 1862, we had Papers at this Institution upon the question of steel rails, and we had it solemnly stated in the discussions, that the suggested economy in their use, was an apparent economy only, for, when interest was taken into account, having regard to the extra cost of steel over iron which

[1] Proceedings of the Royal Institution, vol. viii., p. 314.

must *always* prevail, it would never pay to employ steel rails, and the true use of steel in the permanent-way would be found in points and crossings; while now the wrought-iron rail is more costly than the rail made of the superior material steel. Important as the subject is, time compels me to refrain from further allusion to it, and forces me to conclude this head of my address with the physician's (Abernethy's) well-known advice to his patients, "Read my book," *i.e.* my lecture at the Royal Institution, to which, however, I must add one word, and that is I must here refer to the important improvement, made since the date of that address by the process of Messrs. Thomas and Gilchrist, by which it has been rendered possible to employ successfully, in the production of steel, iron derived from ores which, prior to the date of this invention, had been found wholly inapplicable for the purpose.

In the manufacture of pig-iron, improvement has been effected by increasing the dimensions of the furnaces, and, (thanks to Mr. Cowper in the outset, followed by others,) by increasing the temperature of the blast, by the closer application of chemistry to the industry, by the total closing of the bottom of the furnace, and by the increased use of the waste-gases; from these improvements an economy, and a certainty of production have resulted, leaving little to be desired. It is to be hoped also that the attempts will be successful which are being made to convert to various useful purposes that great waste-product, blast-furnace slag.

I have varied the usual order, by taking the Iron Age before the Bronze. To revert to the Bronze—the mysterious influences, that a very small percentage of some material, will exercise upon the quality of the great bulk of another material, with which it may be united, are well shown in the case we have been considering, that of steel, where a few tenths of one per cent. of carbon added to the iron suffices to change the iron into steel. We are not surprised, therefore, when we find that other metals, may have their qualities improved, for many useful purposes, by judicious alloy; and in this way the metal, copper, so long used in its alloyed condition of "gun-metal," has within the last few years been still further improved by associating it with other substances, and thus making it into the now well-known articles "phosphor-bronze," and "manganese-bronze"—very useful materials to those of our members engaged in the construction of machinery.

So closely allied to the consideration of the nature of a material, is that of the means of producing it in the desired form, that one naturally passes thereto. As long as small masses had to be dealt

with, and as long as those masses were of a plastic character, it was possible to successfully employ the hand-hammer, the sledge-hammer, and later on, the steam-hammer; but with the increased dimensions of the main-shafts of engines, and of the solid forgings for the tubes of cannon, obtaining at the present day, and having regard to the fact that these are composed of "steel," the effect of light steam-hammers is not merely negative for useful purposes, but is absolutely harmful, tending to develop internal flaws; and in my judgment the forging of very large masses by pressure without blow is preferable. A few years ago Sir Joseph Whitworth devoted his attention to devising some means of dealing with the steel whilst in a molten state, and so as to diminish the size of cavities containing imprisoned gases. I think the time is not far distant when some such means will be employed to produce (without variations in the constituents of the steel), a casting that shall be practically, if not absolutely, free from blowholes; so that such casting when afterwards forged by pressure, and not by inadequate percussion, may be thoroughly trusted to contain no latent defect.

One of the difficulties that was foreseen, in the outset of the employment of steel for tires, was the difficulty of welding the ends of a steel tire-bar, after it had been bent into the hoop form. I was, I believe, one of the very earliest to suggest the making of tires in the hoop form, and so not only to avoid the cost and risk of welding, but also to avoid the waste upon each tire-bar, arising from what was known as the "crop end." I read a paper on this subject, before section G of the British Association at the Birmingham meeting in 1865, and I then prophesied, that in a very few years from that time, a welded tire would be unknown; a prophecy which has been amply fulfilled; but I also pointed out, that so far from its being the right way to set about the manufacture of a hoop, by beginning with a straight bar, then bending it, and then welding it; the manufacture in the hoop form would be the proper one to adopt, even if the object were eventually to produce a straight bar, such as a rail, for in producing the hoop in this way the rolling would be continuous, and when the hoop was cut and flattened out into a straight bar there would be no "crop end," no waste therefrom, and no fear that in order to render the waste as little as possible, there would be retained at the ends of the rail—its most vulnerable parts—metal of an inferior character.

In this same Paper, I showed that the right way of making boiler-shells, and boiler-flues, would be by the hoop system and by

endless rolling, thereby avoiding the longitudinal seams, which, after the very best has been done that can be done, reduce the effective strength of the boiler-plate by one-fourth or one-third, and commonly reduce it by one-half. I will refer my hearers to vol. xx. of the "Engineer," p. 200, where the Paper and the accompanying diagrams are given.

The subject of steam-boilers brings one naturally to the consideration of that which still remains the great source of motive power—the steam-engine. Here since 1862 it is difficult to point to any great substantive novelty, but these machines have been more and more scientifically investigated, and the results of such investigation have been practically applied, so as to produce the anticipated advantages.

The increase in initial pressure, the greater range of expansion, the steam-jacketing of the vessels in which the expansion takes place, have all led to economy, so that double-cylinder non-condensing engines are now currently produced, which work with a consumption of only 2¼ lbs. of coal per gross indicated horse-power per hour, or 2·7 lbs. per horse-power delivered off the crank-shaft, equal to 83 millions of duty on the Cornish-engine mode of computation; and when these high results are augmented by the employment of surface-condensation, an indicated horse-power has been obtained for as little as 1½ lb. of coal, and it is commonly obtained, in daily work, for from 2 lbs. to 2½ lbs.

But the engineer using steam as his vehicle, in a heat-motor, still has to submit to the chagrin, of seeing the largest portion of the heat pass away unutilized. This defect has for years attracted the attention of scientific engineers. Indeed, we know that more than thirty years ago our lamented friend, William Siemens, devoted his great powers to the production of a regenerative steam-engine, by which he hoped to decrease this loss, but he was not successful in producing a practical machine. The labours of those, who, following Stirling, have endeavoured, by employing air as the vehicle of heat, to obtain better results, have resulted in producing very economic machines, and machines of practical utility, but hitherto only applicable where small power is required. There is, however, another form of heat-motor, which, while vainly essayed during fifty years, has within the last eight years come into common use, and the application of which, in cases requiring anything up to 30 I.HP. is daily increasing. I need hardly say that I allude to the gas-engine. By a happy change in the mode of burning the mixture, and of utilizing the heat thereby generated, the injurious shock of the

early forms of gas-engine, and the large consumption of gas which caused these earlier forms to be discarded after trial, were obviated. A notable instance being in the gas-engine for propelling the fan that ventilates this room, which, after a short time, was pulled out and was replaced by an hydraulic engine. According to the "Mechanics' Magazine" of August 10th, 1866, p. 87, the French engineer who tried a Hugon gas-engine found that 74 cubic feet of gas per I.HP. per hour were required; this consumption is now replaced by the 20 to 23 feet per I.HP., which suffices for the engines of the present day. With the low price of gas commonly prevalent in England, this consumption does not cost more than some seven-eighths of a penny per horse per hour. I am aware it may be said that with coal, even at the London price of £1 per ton, I might use a steam-engine having the low economy of 8½ lbs. of coal per I.HP. per hour before I should be called on to spend seven-eighths of a penny per I.HP. per hour for fuel; you would be astonished to hear, however, that in an investigation instituted last year by the Corporation of Birmingham, when considering whether they should approve of a proposal to lay down power-distributing mains throughout their streets, it was found on indicating some six non-condensing steam-engines taken indiscriminately from among users of power, and ranging from five nominal HP. up to thirty nominal HP., that the consumption in one instance was as high as 27·5 lbs., while it never fell below 9·6 lbs., and the average of the whole was as much as 18·1 lbs. This heavy consumption largely arose from a prevalent defect, one I have frequently pointed out, that of too great cylinder capacity; for unless a non-condensing engine is admirably designed, and made with the object of using very high expansion, there is nothing so wasteful as the employment of that which the buyer of an engine looks upon as an advantage—very great cylinder capacity. The result of such a construction being that the initial pressure of the steam, in the cylinder of the ordinary small power non-condensing engine, is not more than 20 to 30 lbs. above atmosphere, a condition of things, wholly incompatible with economy. But even assuming that the user of a gas-engine, were entitled to compare it with a non-condensing steam-engine consuming only some 5 lbs. of coal per indicated HP. per hour, and demanding, therefore, at one shilling per cwt. only one halfpenny for the purchase of coal, this difference of three-eighths of a penny in cost of fuel is well repaid by the saving of boiler-space, of the wear and tear and of the renewal of the boiler, of the consumption of coal while getting up steam, and during meal times, and the

saving in the engineer's or stoker's wages; and on public grounds there are the advantages of freedom from boiler explosion, and of cessation of smoke-production.

I have spoken of gas-engines hitherto, as though, like hot-air engines, they were necessarily restricted in their dimensions, but this is not so; engines are now being made to develop 50 HP. Further, be it remembered, that when used on a large scale, so that it would pay to have an attendant devoting his whole time, there is no need to work them with illuminating gas from the street mains, they can be driven by producer-made gas on Dowson's system, and when worked in this way, a pound and a half of "culm" will give one HP., and one lad is sufficient to manage a gas-producing apparatus of a size adequate to provide for engines developing 300 I.HP. I ventured to say, at the meeting of the British Association at York in 1881, when giving a partial review of that which had happened in engineering, in the fifty years from the foundation of the Association, that unless some wholly unexpected improvement were made in the steam-engine, those who lived to see the celebration of the centenary of the Association in 1931, would find the steam-engine had become a curiosity, and was relegated to museums, for I could not believe steam would continue to be the vehicle, for transmitting heat into work.

A motor has been recently tried where no fuel is employed directly, but where a boiler, being filled with water and steam under pressure, has its heat maintained by exposing caustic soda, contained in a vessel surrounding the boiler, to the action of the waste steam from the engine, the result being that as the moisture combines with the caustic soda, a sufficient heat is developed to generate steam and to keep the engine working for some time. The trials have been made with the motor for propelling a launch, and I believe with one for working a tramcar. It may be, we have here a source of power, in a portable form, useful for the purposes I have mentioned, and for others analogous thereto. It hardly needs to be said, however, that fuel has eventually to be employed to drive off the moisture from the soda, and thus to bring it back to its caustic condition.

I cannot pass away from this brief allusion to heat motors, without expressing my gratitude to those lecturers who addressed us "On the Mechanical Applications of Heat" last session, and especially to our Member, Mr. William Anderson, for his lecture in that course "On the Generation of Steam and the Thermo-dynamic principles involved." Let me tell those of you, who do not already know it, that Mr. Anderson has still three lectures

to deliver out of a course of six lectures which he is giving at the Society of Arts on "The conversion of Heat into useful work," and permit me to advise all those Members of this Institution who can possibly do so, to attend, (as I hope to be able to do,) the remainder of those most clear and instructive lectures.

There is one indisputable heat-motor I have omitted, viz., that wherein power is obtained directly from the sun's rays. Attempts have been made during the last twenty-two years in this direction, but we enjoy so little powerful sunshine in England, and the question is still in such a thoroughly experimental stage, that I think I must not take up your time by any consideration of it.

With respect to other motors, viz., those driven by wind, or by water (not commonly looked upon as heat-motors, although in truth there would be no such agencies without heat) but on these there is not time to say much. I will merely call your attention to the improvement in waterwheels in France, an improvement by which it is asserted that as much as 85 per cent. of all the energy residing in a low fall of water has been converted into power: a result due to the decreasing of the speed of the periphery of the wheel, and to the making of the buckets very narrow and of great depth. In turbines, also, there has been considerable development in these twenty-two years, and they now take their place as very efficient motors, possessing many advantages, where, on the one hand, a very high fall of water has to be utilized, or where, in the case of a low fall, great differences in the working head, and in the level of the tail water, have to be provided for.

With respect to the power of the tide; I, for one, have been very much fascinated with the scope there appeared to be, for engineering, in utilizing tidal power, especially where there was a great ebb and flow, and I have on former occasions expressed some sanguine opinions as to the practical use that could be made of this source of power; but being called upon to look into the question, I found, that as in these days of competition, very few businesses needing motive power, can allow their plant to remain idle for nearly half the working day, and as there is a great objection to remedy this by utilizing both the night-tide and the day-tide, so as to make a full working day, this defect alone prevented the satisfactory use of tidal power. Further, when it was sought to preserve continuity of action, by providing a series of reservoirs, the outlay needed was so large, that the mere interest on it, would pay for the fuel for a steam-engine. I am afraid, therefore, that except for certain cases, such as pumping of water into a reservoir, or charging of so-called storage batteries, or matters of

that kind not connected with ordinary manufacture, this source of power is not likely to compete commercially with heat-motors, until coal is very much dearer.

The periodic intermittency of tidal motors being a sufficient bar to their employment, it is not to be wondered at that the (proverbial) uncertainty of the wind, causes motors which have to be driven by it, to be disregarded, as substitutes for the steam-engine. I have, however, said elsewhere, I think it is well worth considering whether wind-motors could not be employed as adjuncts to steam-engines, diminishing the load upon them or laying them idle altogether, according to whether there was a light or a strong breeze blowing.

The uncertainty as regards obtaining a sufficient breeze, which prevents the wind from being a trustworthy source of power, aggravated by the further uncertainty as to the direction in which the breeze would blow when it did come, has rendered the air, as a medium for navigation, even more untrustworthy. During the last few years, however, a new locomotive agent, has been prominently brought forward—I mean a balloon, capable of being propelled and steered, or, as it has been termed, a "dirigible" balloon.

Many persons have fancied that it is impossible to propel a balloon through the air; but this, as I need hardly tell an audience understanding mechanics, is entirely a fallacy. The reasons for the failure of the early attempts to steer balloons were practical and not theoretical, and they have been removed by recent mechanical improvements.

The first really successful effort was made by Mr. Henri Giffard, the ingenious inventor of the injector, all reference to which I have omitted, however, because of its being slightly anterior to 1862. In 1852 this gentleman ascended in an elongated balloon propelled by a steam-engine working a screw propeller; and he was followed twenty years later by Mr. Dupuy de Lome, (the late Government naval architect of France,) who, however, used hand power. The speed through the air in these trials was about 6 miles an hour, and the steering-power was fully obtained.

Taking these and other experiments as data, my friend and fellow Member, Dr. Pole, (to whom I am indebted for the information on this subject,) published in our Proceedings in 1882,[1] a full investigation of the problem, which led him to believe that a velocity of 25 to 30 miles an hour might be attained; and since that time further

[1] Minutes of Proceedings Inst. C.E., vol. lxvii., p. 369.

trials have been made in France by Messrs. Tissandier, Renard, and Krebs, who, using electric power, have already accomplished half the predicted speed, with a promise of much further development, when more experience has been gained with the practical details.

I fear that the rapid and changeable motion of the medium, in which balloons have to move, will prevent this mode of locomotion from ever having a wide application, but there may undoubtedly be particular circumstances, in which it would be useful, such, for example, as the exploration of new countries, or as the present Egyptian campaign. I strongly suspect that if our lively neighbours, instead of ourselves, had been invading the Soudan, they would long before this have had a "dirigible" balloon looking down into Khartoum.

Let me refer all those who take an interest in this question to an earlier article by Dr. Pole, which was published in the "Quarterly Review" of July 1875. This article is still considered a "classic" on the subject.

Next to the subject of motors, should have come, (had I not been led captive by a balloon,) that which I am now about to mention, *i.e.* the Transmission of Power. Taking this in the restricted sense, of the transmission from one part of a machine to another, commonly with the object of varying velocity, one may point to the increasing use of multiple rope-driving gear, in lieu of belts, to inclined spur gear for diminishing noise, and to that kind of frictional gearing to which the name of "nest gearing" has been given. Here the frictional driver being acted on at the two opposing sides, strain is removed from the bearings, and the liability of one of the frictional wheels to stand still, and to be fatally injured by having a flat rubbed upon it, is avoided. In that very important branch of transmission, wherein power is taken to long distances, however, we have the development of hydraulic transmission, as is evidenced by the fact of pipes being now laid down through our towns, for supplying water under the 700 lbs. on the square inch pressure for motive-power; we have companies authorised, if not at work, for laying down pipes to distribute compressed air; we have now by reason of the improvement in gas engines, the ability to lay on power in every town illuminated by gas, which practically means every town and large village; and, we have in New York and in some other cities of the United States, high-pressure steam, conveyed in mains below the streets, to be used both for power and for heating, for which second purpose, however, it should be remembered the contents of a gas main are equally available. I will not touch upon other

modes, except just to mention the rope system at Schaffhausen;[1] but I think we may take it as clearly established, that we are, day by day, becoming more alive to the benefit, where little power is required, or where considerable power is required, but only intermittently, of deriving that power from a central source.

Under the heads of motors, and of transmission of power (both of them, it is true, eminently subjects for the civil engineer) I have spoken of water, but there is another way in which water is used; the way with which engineers and the public are more familiar, viz., its employment for the supply of our towns, which I have not as yet mentioned. Except in the magnitude of the work, and the excellence of the design, of which Mr. Hawksley's new Liverpool waterworks now being constructed may well stand as a typical example, there is not much to say as regards progress in those waterworks which are dependent upon storage. Indeed there is nothing very marked, to point to in these twenty-two years in the way of improvement in pumping-machinery. Having visited the United States, and Canada, twice within the last two years, and having seen the waste of water that takes place in both those countries, (a waste which not only causes the mains to be incapable of keeping up the pressure under the excessive draught, but renders sources of supply insufficient which otherwise would be ample for years to come,) I cannot but rejoice at the progress that has been made here, in the matter of house-fittings, by which waste has been greatly checked, and the risk of contamination, that formerly existed with certain closet-fittings is ended. This question of house-fittings, has always been a difficult one, and it becomes impossible to be grappled with, by water authorities such as those in the United States and in Canada, *i.e.*, municipal authorities afraid of offending the voter. We owe it, however, to Mr. Deacon, the engineer of an English municipal water authority, that it is now possible to deal with the correction of household fittings, at a minimum of cost, and, what is equally important, with a minimum of annoyance to the householder. By the employment of the Waste-Water Meter,[2] situated under the flagstones of the footway and controlling a group of houses, we can find out the total waste in the whole of those houses, and on the mains supplying them; then can localise that waste so as to attribute its true proportion to the houses that are the offenders, and can also attribute the proportion, if any, to the pipes of the suppliers of

[1] Minutes of Proceedings Inst. C.E., vol. xlix., p. 23.
[2] *Ibid.*, vol. xlii., p. 143.

water. Having ascertained these facts, not only can the suppliers of water, cure the defects in their pipe system, but they are enabled to cure the household waste, not by the expensive and annoying process, of an inspection of the fittings throughout the whole district, involving the annoyance of say ninety householders whose fittings are in perfect order, to detect the ten householders whose fittings are in a reprehensible condition; but by the mere visitation of these ten, who are in default, and who cannot therefore complain of the visitation. With respect to the purity of the water-supply, this, although it relates to water, is so "burning" a question that I fear to touch upon it. I believe that in most of our towns the supply is satisfactory, but I do believe, in spite of the alarm raised by the suggestion of double mains, we might do well in many cases, where there is a pure but limited supply, to have a dual system of mains, and thus to distribute the pure water separately, and for potable purposes; I am not about to hold up the water-supply of Paris as an example for us to follow on all points, but the Parisians at least, have recognized the expediency, of thus sorting their supply, when that supply is of varying quality, and when the best of it is limited in quantity. In cases where there appears to be no thoroughly satisfactory source of water, the experience of the efficacy of iron purification, as practised at Antwerp, does hold out very considerable promise.

Gas likewise has been alluded to under the heads of Motors and of Transmission of Power and of Heat, but I now desire to say a few words in connection with it under its more ordinary aspect, that of a distributed illuminant.

In the year 1862, the price of ordinary coal-gas in London was from four to five shillings per thousand cubic feet; the illuminating power required was that 5 cubic feet of the gas burnt in a specified burner, in one hour, should give a light equal to twelve sperm candles, each burning 120 grains in the hour. At that time the consumer was, as it was facetiously called, "protected" by restricting the company to a maximum statutory dividend. Obviously, so soon as this dividend was earned, all incentive to improvement was removed. One of the few cases in which recent legislation, relating to private companies supplying public wants, can meet with the approval of the political economist, was that which a few years ago first recognized it would be well for the private company, and for the public, that the ordinary incentive of increased profit for increased exertion should remain, and that introduced, in certain gas undertakings, the "Sliding Scale." This provided for a normal price, and for a normal dividend, but

allowed the company to rateably increase this dividend in accordance with a decrease in price below the normal. Under this wiser legislation, sixteen candle-gas is sold in London for as little as two shillings and eightpence per thousand cubic feet. But illuminating gas has to be considered by the engineer under two distinct heads; one, its manufacture and distribution; the other, its utilization; this last, it is true, is but to a small extent in the hands of those engineers who have the charge of the first. Considerable progress has, however, been made of late in illumination, largely, it is true, due to a greater liberality on the part of lighting authorities, and the use thereunder of multiple burners in street lanterns, but to a considerable extent due, to that much more to be desired improvement, whereby a greater amount of light, is obtained from the same volume of gas. The regenerative gas-burners, and other modes of burning, into which time will not permit me to enter, promise to largely increase, (it is said, even to more than double) the candle-power per cubic foot of gas burnt. Such improvement as this, is undoubtedly of great moment, not only on the score of economy, but on the sanitary ground of diminishing the amount of products of combustion, poured into a room, in relation to the light therein afforded. It need hardly be mentioned that the decrease in cost, and the increase in profits, are largely due to the application of chemistry to this manufacture, by which application the former nuisance-creating by-products have been turned into sources of revenue, and into fertilizers for our fields. I have also in the most cursory manner mentioned gas as a means of distributing heat; but a word should be said about those valuable improvements in gas-furnaces—I do not mean the Siemens furnace—which have enabled coal-gas, to be applied to the melting of even very refractory metals, by means of a most inexpensive plant. Nor have I spoken of those other applications, where either burnt with coke (it may be of the very coal from which the gas itself was derived), or caused to raise incombustible bodies to incandescence, it forms the cheerful and smokeless substitute for a smoky coal fire, or is utilized for the purposes of domestic cookery. In this latter case, however, if absolute cleanliness and ventilation are not preserved, there will (as the unhappy traveller, compelled to temporarily sojourn in the "limited" hotels of the present day finds to his cost) be one universal dirty gas-oven flavour, impressed upon all his food, be it the homely leg of mutton, or the lordly haunch of venison.

Although it is quite certain that the first suggestion for using liquid fuel, (notably tar, to aid in heating gas-retorts) must date

long before 1862, yet the great development of the mineral oil industries since that time, has led (and especially in Russia, where such enormous quantities of oil are obtained), to the employment of this material as a fuel in furnaces and in steam-boilers. Next to the infinitely divisible forms of gaseous and of liquid fuel comes, as I have said elsewhere, the dust fuel introduced by Mr. Crampton. In the use of any of these three forms, regularity of mechanical supply is a condition involved; and any one of these three, therefore, irrespective of all other considerations, is desirable because it is a means of dispensing with that most unsatisfactory form of labour—"stoking," dispensing also with the production of smoke, and with the diminution of maximum effect attendant on the hand-feeding of coals, whereby the condition of the fuel in the grate, and its temperature must be ever varying. Having regard to these advantages which are to be obtained in using oil, and to the cheapness of the material in Russia, one is not surprised to find that there are lines of steamers on the Caspian, worked entirely by liquid fuel, and that the same kind of fuel is used to fire the locomotives in many districts.

I have mentioned the improvement in small furnaces worked by illuminating gas; but I am not entitled to bring within my period the regenerative gas furnace, that great invention, made by our lamented friend Sir William Siemens, with whose name in this matter should be coupled that of his brother, Mr. Frederick Siemens. This latter gentleman by a course of study, has recently discovered, and it is an interesting scientific fact, that so far from the heating power of the flame being increased by its confinement within narrow chambers, and by its being brought into contact with the material to be operated upon, such arrangements only diminish that power, and he has further found that this discovery can be usefully applied in practice, by keeping the roof of a regenerative gas-furnace at such a height above the hearth, on which the materials to be heated lie, that the flame can traverse from one side of the furnace to the other, free of contact with the roof above, or with the materials below.

Very excellent economic effects and a high heat, it is stated, have been obtained, by causing the outgoing products of combustion, to give up their heat to the incoming cold fuel. I have seen such furnaces in operation, making steel by the hearth process, and it is the fact that the chimney has been without a trace of red glow within it.

The natural oils which are used as fuel, and to which I have referred, are rarely employed in their crude state, as obtained from

the wells; but they all undergo more or less refining before use. There is another natural fuel, however, which has been discovered in America, and within the last few years largely utilized—this is the gas obtained from wells in a manner similar to that in which the oil is obtained. It is a marsh gas of high calorific power, and is, in certain parts of the United States, being used very largely for domestic heating, for the heating of furnaces of every description, including those for the manufacture of plate-glass and of steel; it is also being employed for the manufacture of lamp or carbon black, and for the carbon points for electric lighting. It is stated that within a radius of 20 miles from the town of Pittsburgh, taken as a centre, there are twenty-five wells, each producing 3,000,000 cubic feet per twenty-four hours, and that the produce of the whole of the wells at present opened up is 100,000,000 cubic feet of gas per day. To my mind this is one of the most perfect fuels which can be imagined: it requires no preparation, but can be, and is, used in the same state as that in which it issues under a high pressure from the wells; it can be mechanically controlled with the greatest nicety, and when properly burnt, is entirely free from smoke or similar defects. When employed in the Siemens regenerative furnace, the producer which is necessary, where coal is used, is entirely dispensed with.

Probably there is no function of the engineer, in which the public feel their interest to be so immediate, as when he is engaged in supplying to them their food. Prior to 1862 it is true that steam-ploughing, and various cultivating and reaping machines were in existence, but they have been much developed since, and if the English farmer, is to be saved while growing grain, it will be by reason of his availing himself of the labours of the engineer. Unhappily for that farmer, he has not the monopoly of the engineers' services, the products of whose skill are as fully appreciated for the cultivation of the enormous corn districts of the far west, by the farmers there, as they are in England. Again, unhappily for our farmers, the engineer by his railways and by his improved steamships, renders it possible for the grain grown in the United States, and in Canada, to find its way to our markets, at a cost for freight so trifling, as not to equal that which, a few years ago, would have been paid for transit from one part of England to another.

It would not be right to pass away from improvements in agricultural engineering, without referring to that which is a distinctive novelty since 1862. I mean the fast-becoming-general

combination with the reaping-machine of string sheaf-binding apparatus.

I am afraid I cannot claim for the engineer that recent introduction the "Silo." He is, however, turning his attention to the improvement of the details, and is showing how mechanical appliances can be advantageously used in connection with them. By the aid of silos, our grass crops may be saved in the green form, notwithstanding wet and unpropitious seasons; but those who still prefer sweet and sound hay may hope, that the engineer will devise some practical mode of artificial drying, and thus enable them to obtain it even in the absence of the sun, and may also hope that the adoption of similar means will save our grain crops, although the harvest may be followed by steady and continued rain.

But a question may arise, whether, except for horse-feed, we need trouble ourselves about silos or hay, having regard to the fact of the great development since 1862 of refrigerating machinery, which renders possible the importation of frozen meat from Australia, and from other countries. I hope for the sake of the English farmer that there will still be many who will be prepared to pay for English-grown beef and mutton, and for real milk and real butter, and that they will not be tempted by cheapness, to substitute milk of condensation, and butter of oleo-margarine. But I hear the poor farmers are now threatened by a flood of steamboat-transported milk, from Holland.

While on the question of food, the temptation is great upon me to refer to the wonderful improvements that have been made in "milling" since the year 1862; but I must refrain from this and from all other remarks upon the question of food, except to remind you that, if the providing of food is one of the great social problems of the present day, another is how to get rid of sewage. This latter problem, however, has been so fully dealt with by my immediate predecessor, Sir Joseph Bazalgette, as to leave me nothing to say.

There are two other most important subjects involving large commercial interests, and in one of the subjects, at all events, great modern invention, upon which, fortunately, I need not say one word, as in respect of the first of these—electricity—I can refer you to the volume of lectures delivered here in 1883; and in respect of the second—tramways—I can refer you to the Papers which, with the discussion upon them, have already occupied three evenings of this session.

I see that our allotted time is already exceeded, and I am thus

compelled to leave unsaid, much which I should have liked to have told you, touching many things which almost every one of you must remember, (each in his own special line of engineering) as being of general interest, and novel since 1862; but the subject upon which I have undertaken to speak is so vast, that even with the severe limitation, which as I stated in the earlier portion of my address I had imposed upon myself, I find omission is inevitable.

Now let me say a few words—they shall be very few—about our Institution. We heard at the Annual General meeting of the great increase in our numbers. This is no doubt highly satisfactory, but, according to my judgment, not satisfactory merely because of that increase in numbers, but because it is a proof we are doing work that is appreciated by engineers—if our work were not appreciated they would not come to us. And therefore, although I value the growth in our numbers for its own sake, I value it still more as evidence of the good work we are doing, and that I trust we shall continue to do.

You have made me for my term of office your nominal head, and in so far as it lies in the power of the President to promote that good work, I assure you that every effort of mine shall be given to it. If I fail, it will be from inability, and not from the want of earnest will, or, assuming I preserve my health, of industry in my office. But my efforts alone will not suffice; the President is powerless, unless he is helped by the members. Remember, each one of you that it is your duty—pardon me saying so—to bring before this Institution every subject of interest connected with our profession, of which you have experience in the course of your practice, and to attend the Meetings as frequently as you can. Do not, after a hard day's work, yield to the tempting but immoral suggestion of going home to your wife and family, but come here; attend the Meetings; take part in the discussion —and, may I say, take part in it for a useful purpose. Do not let any man get up merely because he thinks he ought to be heard on a particular subject. Having nothing to say, let him say nothing. It is past counting the number of times I have heard the remark, 'I think we are all greatly indebted to the Author of this Paper.' A man who talks like that ought to be fined. The meeting as a whole have thanked the Author of the Paper, or are about to do it, and we do not wish our Transactions to be interlarded with such observations. I should think the shorthand-writer has a sign for that phrase. What we really want is this: we desire that each member should ask himself, "Have I anything useful to say on this subject? If so, I will

say it, and will do so as concisely as possible consistently with clearness." I know it has often been proposed that we ought to have a limitation of time, and that each speaker should be restricted to a certain number of minutes. I think that is wrong; because some men, who can instruct us in the subject under consideration, we should like to listen to for twenty minutes, while another man could say all that he has to say in two minutes. Why, then, give each of these a hard and fast law of five or ten minutes? I think the Meeting must trust to the President; while the President, in order to have authority, must be supported by the Meeting.

I hope you will pardon me for these words of admonition. I know they come ill from a man who is only a week old in his office, but then he is not wanting in age in other ways, and believe me that they arise solely from his desire that the Transactions of the Institution, both in the Papers selected by the Council, and in the remarks on those Papers offered by members and visitors, should be worthy of that which has preceded—worthy of the Institution itself. I will ask you, in conclusion, to pardon me for the time I have spent in this address. It has run to a far greater length than I had intended, but I assure you it has been unavoidable. As I have said, believe me that I will do all in my power to further our joint interests, and in return, and to this end, I ask you to give me the assurance that I shall have your hearty support.

On the motion of Sir Charles Hutton Gregory, K.C.M.G., Past-President, seconded by Mr. Hawksley, Past-President, it was resolved unanimously, "That the best thanks of the members be tendered to Sir Frederick Bramwell, for his interesting and valuable Address, and that he be requested to allow it to be printed in the Minutes of Proceedings."

20 January, 1885.

SIR FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(*Paper No. 2024.*)

"A Comparison of British and Metric Measures for Engineering Purposes."

By ARTHUR HAMILTON-SMYTHE, B.A., M. Inst. C.E.

SOME of the existing systems of measures, such as those of time, angles, velocity and electricity, are practically international. This Paper may therefore be limited to comparing the advantages for engineering purposes of those measures of length, surface, capacity, weight, and pecuniary value, adopted in England, with the metrical and decimal systems of the same classes of measures.

The system of arithmetical notation used by all civilized nations is decimal; consequently all decimal systems of measures have the advantage over others of dispensing with the compound rules of arithmetic, and of facilitating the use of logarithms in engineering calculations. Among decimal systems of measures, the metric system has the advantage of being already used by 240,000,000 of people, with whom 60 per cent. of the foreign trade of England is carried on, and of all its terms being correlated and systematically derived from one convenient, well known, standard measure of length. The natural character of the metric unit, and the accuracy, or otherwise, of its relation to the meridian is practically immaterial. The collection of measures used in England for engineering purposes is partly duodecimal, partly decimal, chiefly binary, and generally unsystematical. Some British measures have the advantage over all decimal measures of being capable of finite ternary subdivision, but this advantage is of comparatively little practical importance.

England and the United States of America hold at present such a prominent position in the manufacture of engineering machinery, and material constructed to British scales of measurement, that a considerable practical advantage is on that account derived from

the use of British measures in engineering works. The capital invested in machinery constructed to manufacture to sizes of British measurement is very large, and the literature on engineering subjects expressed in terms of British measurement is most extensive and valuable. English and American engineers have their minds saturated with guiding or standard dimensions expressed in British measures and ready for application; so that the substitution of other measures in their general practice would prove a source of considerable personal inconvenience to the current generation of engineers in England and the United States. Most British measures in common use have the great advantage of being already familiar to the masses of the English and American people, and to the large number of skilled workmen which these people include.

As regards the depreciation in value of English engineering literature, written in terms of British measurement, that would ensue on the introduction of metric measures, it may be remarked that, long before the existing generation of English and American engineers passed away, the gist of the information contained in English engineering books would be translated into the international language of measurement. The question of the depreciation in value of costly machinery, constructed for manufacturing articles to scales and exact sizes of British measures, is more difficult, and the loss and inconvenience from such depreciation must form a considerable set-off against the advantages to be derived from a general adoption of the metric system. It must be remembered, however, that the progress of improvement in machinery, and the wear and tear of existing machines are so rapid, that in a comparatively few years most of the existing individual machines of this kind would either be worn out, or have become obsolete, from other causes than a demand for articles manufactured only to regular metric sizes.

Both the metre and the British standard yard have the advantage of being the approximate length of a human stride, which has always been the readiest and most extensively used natural unit of linear measure for engineering field-work. The length of a metre is about the limit to which a human being can conveniently place his hands apart when measuring with accuracy on a vertical surface.

It may be observed, incidentally, that the British foot is, strictly speaking, not a British standard measure, but is simply a ternary subdivision of the standard yard, and is itself divided duodecimally into inches, while the inches are again divided binarily and frac-

tionally into quarters, eighths, and sixteenths. In much actual practice the foot is not even adopted as a unit of linear measurement; for instance, most carpenters use a two-foot rule, and having found the number of lengths of their two-foot rule contained within the length of the plank they are measuring, they proceed to compute this length in feet by doubling the number of two-foot-rule lengths they have measured, and then adding to this the odd foot and inches and fractions of inches which may go to complete the total length of the plank. A workman measuring with a metre simply measures the number of metres, and reads off at once the decimal parts of a metre which make up the total length of whatever he is measuring. It may be said that the amount of computation required to double the number of two-foot-rule lengths is so small as not to be worth consideration, and that such an objection to measurement by feet is merely fanciful; but for all that it cannot be denied that an additional mental process has to be exerted by a British workman every time he measures a length with a rule which does not coincide in length with the unit in which he expresses the total length measured. A plank can be measured with accuracy with a metre in two-thirds of the time required to measure it with a two-foot rule, and in one-third of the time required with a one-foot rule; and in a carpenter's day's work the sum of these differences of time is by no means unimportant.

The British inch is much too large to serve as the lowest integral unit in a scale of linear measurement, and even the sixteenth of an inch is too large for minute work. The instructions so often given to a British workman to make an article "five-sixteenths full" or "bare three-eighths" are hardly compatible with precise accuracy of workmanship. The millimetre is, on the other hand, a very convenient unit for ordinary minute work, and its decimal subdivisions are quite as convenient for microscopic work as thousandths of an inch. Another example of the additional computation involved by English practice is the taking of levels for building work in feet and tenths and hundredths, and the necessary translation of the resulting dimensions into feet, inches, and fractions of inches for the workmen.

For all ordinary field-levelling the division of a levelling-staff into decimetres and centimetres only is sufficiently minute. The centimetre can easily be binarily subdivided by ocular estimation, and the practical advantage of reading to the hundredth of a foot on a levelling-staff in straightforward levelling is very doubtful. Certainly more rapid, and probably quite as accurate, levelling can be done in a day with a staff subdivided in centimetres as with a

staff divided into hundredths of a foot, and the practical accuracy of metric levelling when applied to building work will be greater, as the dimensions given to the workman will be in the terms actually noted through the level.

The chain used in the metric system for field-work is usually 20 metres long, or 4½ inches shorter than Gunter's chain, though for difficult country a 10-metre chain is preferable. Assuming that the length of Gunter's chain is that found most convenient for field-work, the twenty-metre chain has practically the same advantages in that respect, but the use of a twenty-metre chain involves additional computation owing to the number of arrows held by the rear chain-man having to be doubled to get the number of dekametres to be entered in the field-book. The use of a ten-metre chain of course does away with this objection, and it has the same advantages as regards direct correlation with the hectare as Gunter's chain has with the acre. The twenty-metre chain has the advantage over Gunter's chain that it is capable of subdivision into the smaller linear measures, whereas Gunter's link is the lowest integral subdivision of Gunter's chain and is too large for any work but land-measuring.

For purposes of engineering calculation, it is obviously desirable that the unit of linear measure should have its multiples and submultiples arranged in accordance with the universal system of arithmetical notation, that it should be the basis of the units of measure of surface, capacity, and weight, and that it should be as international as possible. The metre complies much more fully with these conditions than the yard. In all questions relating to the pressure of materials upon surfaces, the intimate correlation existing in the metric system between the units of measures of weight and capacity is valuable, and hydraulic calculations are much simplified thereby. Between the English horse-power of 550 foot-pounds per second and the metric horse-power of 75 kilogrammetres per second there is little practical difference in point of convenience, but it is highly desirable that scientific units of this nature should be international.

An engineer using the metric system has practically but one denomination of measurement to deal with throughout his work, both in the field and in the office; all his measurements and the scales of all his plans being expressed decimally in terms of a metre. An engineer using British measurement measures a line of works in chains, furlongs, and miles; takes levels in feet divided decimally; gives dimensions for buildings in feet divided duodecimally into inches and in inches divided fractionally; calculates earth-

work in cubic yards; measures brickwork in rods, and land in acres, roods, and poles; measures lime in bushels or barrels, water in gallons, and weighs materials generally in tons, hundredweights, quarters, stones, pounds, and so on almost *ad infinitum.* Then when he comes into the office he plots his surveys in scales of chains to the inch and feet to the inch, and makes his drawings in scales of various fractions of an inch to the foot.

Besides the measures and scales above specified, the English or American engineer has to deal with an infinite number of gauges, trade sizes, and trade and local customs which render comparison of cost exceedingly difficult, and many of which would become obsolete if the metric system were in general use. The habitual employment of British measures debars English and American engineers to a great extent from profiting by the extensive and valuable foreign technical literature written in terms of metric measurement. However perfect they may be in knowledge of foreign languages, their minds cannot, if they have been accustomed to work only with British measures, either grasp or retain with facility, dimensions expressed in metric measures, and they are therefore partially shut out from a very extensive source of professional experience. The advantages of an international language of measurements for engineering purposes are so great, that they may be assumed to counterbalance any advantages claimed on behalf of any new decimal systems based on units of British measurement.

In so much of the routine work of a civil engineers' office as consists in taking out quantities and making estimates, about one-third more work can be done within a given time with metric measures than with British measures, though, of course, the loss of time can be somewhat reduced by the free use of ready-reckoners and tables. On this account engineers accustomed to and using metric measures have an advantage over engineers using British measures. It has been urged as an objection to decimal systems that they are not suitable for binary subdivisions, and alleged that binary subdivision is the most convenient for common purposes. It must be remembered, however, that as all binary divisions admit of expression in precise decimal equivalents there is nothing to prevent binary divisions of a metric unit expressed in fractions, such as $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, &c., being used by those who prefer them. The metric scales for plans are simple and convenient, and have the advantage of enabling the mind to compare very easily the dimensions on plan with the actual distances in nature.

The English practice of plotting plans to scales of so many of Gunters' chains to the inch, expressed in feet, seems to have little

to recommend it beyond the questionable advantage of causing the admeasurement of such plans by the uninitiated to be particularly difficult. In a paper "On the introduction of the metric system into machine shops in America,"[1] Mr. Coleman Sellers, M. Inst. C.E., points out that the metrical scales only admit of a descent in integral vulgar fractions from full size to $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{25}$, $\frac{1}{50}$; whereas the ordinary inch rule furnishes scales of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, $\frac{1}{12}$, $\frac{1}{16}$, $\frac{1}{24}$, $\frac{1}{32}$, $\frac{1}{48}$, $\frac{1}{64}$, making twelve scales in all, as compared with seven metrical scales. Draughtsmen, however, are not confined to the use of either an ordinary inch or an ordinary metre rule in drawing-offices; and in some machine-shops mechanics are, for good reasons, absolutely prohibited from laying a rule on a working drawing, and are instructed to work solely from the figured dimensions.

In the same paper Mr. Sellers states from personal experience that the metric system is not well adapted to the machine-shop because it does not admit of advancing in a series of sixteenths of an inch, which he implies to be the most useful and saleable series for certain articles. No doubt as the "ordinary inch-rule," divided into binary fractions of an inch, has been the ordinary linear measure used by purchasers of certain articles for numbers of years, they will prefer such a well-known series of sizes, and they are therefore found at the present time to be the most saleable; but there is no reason to suppose that purchasers would continue to prefer a series of sizes advancing by the exact metrical equivalents of sixteenths of an inch if the fractional divisions of an inch were no longer in ordinary use as linear measures.

As regards building scales, it seems desirable for simplicity that the scale of $\frac{1}{8}$ inch to 1 foot, or $\frac{1}{96}$, should be replaced by a scale of 1 centimetre to a metre, or $\frac{1}{100}$, and the scale of $\frac{1}{4}$ inch to a foot by a scale of 2 centimetres to a metre, or $\frac{1}{50}$; while such a building scale as $\frac{3}{16}$ inch to a foot can scarcely be held to convey a very clear idea of the relation between the size of the building as represented on paper and its actual size when built.

It has been generally conceded that the maximum advantage from the use of the metric system for ordinary purposes cannot be obtained unless the system is used in conjunction with a decimal system of coinage as measure of pecuniary value; and this applies nearly as much to its use for engineering purposes in the preparation of estimates and in recording the cost of work.

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[1] Journal of the Franklin Institute, November 1880, p. 289. Abstracted in Minutes of Proceedings Inst. C.E., vol. lxiii., p. 442

It has been further conceded that measures of pecuniary value differ from other measures, in so much that for political reasons they can never be expected to become international. The reasons given by the late Sir John Herschel and by Sir George Airy, Hon. M. Inst. C.E.,[1] for preferring the decimal subdivision of the pound sterling to any other decimal arrangement of British measures of pecuniary value appear unanswerable; and if so, the only practical question remaining is the simplest and least unpopular means of bringing such an arrangement into use. It was long ago suggested[2] that by simply enacting the depreciation in value by 4 per cent. of the existing bronze tokens, and thereby making twenty-five farthings legal change for a sixpenny piece, the British currency would be at once completely decimalized. New coins would not be necessary, although the coinage of a silver or nickel ten-farthing piece might be desirable, and the coinage of an increased number of farthings would be necessary in order to provide the odd farthing that would be required, in addition to any combination of pennies and half-pennies in giving change for a sixpenny piece. The existing pennies and half-pennies would serve as four-mil and two-mil pieces respectively in the terms of decimal currency, while popular sentiment would be appeased by the retention of the familiar coins. The alteration of the national measures of pecuniary value, however, could only be effected by compulsory legislation, whereas the general adoption of the metric system, which is already legal though not compulsory,[3] might be brought about to a great extent by its advantages being gradually impressed upon the common sense of the masses through the influence and legitimate pressure of the engineering profession. It has been found, moreover, by the experience of the introduction of the metric system on the Continent of Europe, that the difficulty of familiarizing the working classes with the system had been much overrated. In Austro-Hungary, for instance, the metric system was extensively used by engineers for their own convenience for some years previous to its general introduction. It had become the interest of contractors and workmen to make themselves acquainted with the terms of measurement, in which the plans, specifications, and bills of quantities supplied to them by their employers were expressed, and thus through the medium of the working class a knowledge of the system had been extensively

[1] Evidence given before Decimal Coinage Committee, 1853.
[2] Minutes of Proceedings Inst. C.E., vol. xiii., p. 272.
[3] 27 & 28 Vict. c. 117.

spread through the mass of the people before the system was made legally compulsory for the purposes of general commerce.

Very little progress has been made in England, or in America, within the last twenty years towards simplifying measurement; and the general public in both countries appear perfectly indifferent on the subject, although the actual loss of money, through time wasted on computations and arithmetical studies which the use of the metric system would render unnecessary, must amount to an immense sum annually. Judging from continental experience, it would seem that the best prospect for a reform of measures in England lies in the initiative being taken by those professions most directly interested in the matter.

If British engineers were to commence to take measurements, and make plans and drawings in metric measures, they would probably confer a considerable balance of advantages upon themselves, and conduce to confer great eventual benefit upon their country. Whatever views may be held by individual members of the Institution, as to the advisability or otherwise of using metric measures in their own private practice, the Author submits that the Council might well consider the advisability of taking steps towards obtaining such amendments of the Standing Orders of the Houses of Lords and Commons, as would permit of the dimensions on parliamentary plans and sections, and measures in parliamentary estimates, being expressed either in metric measurement, or in British measurement, at the option of the engineer. If parliamentary plans and estimates could be prepared in metric measurements, English engineers would have practical opportunities of testing the relative advantages of metric and British measures; and such a test would be more useful than any amount of writing and abstract discussion on the subject.

The decimalization of the pound sterling would upset existing arrangements so little, that it is hard to see why it should not be enacted at once, and the decimalization of the coinage would conduce greatly to acquainting the masses with the advantages of decimal computation, but compulsory introduction of the metric system by legislation seems hardly desirable until after the coinage has been decimalized.

The Paper is accompanied by a map, from which Plate 1 has been prepared.

[APPENDIX.

APPENDIX.

To find the weight of water in a tank measuring:—

Ft. Ins. Ft. Ins. Ft. In.		M. M. M.
10 6 × 6 2 × 1 1,	or	3·20 × 1·88 × 0·33
10·5		3·2
6·17		1·88
735		256
105		256
630		32
64·785		6·016
1·083		0·33
194355		18048
518280		18048
647850		1·98528 tonne.
4) 70162·155		
4) 17540·538		
4) 4385·134		
7) 1096·283		
4) 156·611		
20) 39·152		
1·957 ton.		

Discussion.

Sir FREDERICK BRAMWELL, President, proposed a vote of thanks to Mr. Hamilton-Smythe. All should thank him—those who agreed with his views for advocating them, and those who did not, for the opportunity of stating their objections. He would beg the Author to be good enough to explain the tabular comparison given in the Appendix to the Paper. Sir Frederick Bramwell.

Mr. HAMILTON-SMYTHE said he had put forward a mode of calculation, almost at random, with which engineers were familiar. He had taken British measures to find the weight of water in a tank 10 feet 6 inches by 6 feet 2 inches by 1 foot 1 inch, and also the nearest equivalent metric measures—3·20 metres by 1·88 metre by 0·33 metre. He had done this in British measures approximately. He had not converted the cubic feet into the exact number of lbs., but had assumed 1,000 oz. to the cubic foot, the more exact weight being 998·2 oz., or thereabouts. Taking 1,000 oz. produced an error but shortened the process. To effect the calculation with British measures by the shortest way required ninety-four figures. It was done accurately in metric measures with thirty-five figures. Mr. Hamilton-Smythe.

Mr. HENRY MAUDSLAY said the Author had not done himself or his subject justice in putting that calculation in such a form, because British measures of feet and inches would have to be reduced first of all to the lowest denomination before calculations were begun, or else it would be necessary to have a book of decimals, or to work it out in some other form, before arriving at the results which had been obtained. The "5" in 10·5 meant "6" inches. There was thus a mental calculation as to the half of a foot put in decimal terms, and to put measurements of feet and inches and different proportions—eighths and sixteenths—in such a way into figures that the calculation could be commenced, would represent an extra number of figures. Thus, instead of the calculation being as was shown in the tabular comparison, there ought to have been many more figures. He understood that the terms under which the Paper had been brought before the Institution had reference only to engineering purposes, and he remembered, as a result of the International Exhibition of 1851, that Sir Joseph Whitworth and others, including Mr. (now Sir William) Armstrong, prepared scales to metric measure, and to decimals of feet, carefully and elaborately Mr. Maudslay.

Mr. Maudslay. made. At the same time they were rendered easy of comprehension. One remark in the Paper with reference to money opened another question. He supposed it would make very little difference to the British commercially, or as engineers, whether Russia or Turkey ever adopted the metric system or not. He had travelled considerably in countries where the metric system was in operation, and he found that the ordinary people of those countries were enabled to conduct the affairs of every-day life with greater facility, rapidity, and accuracy, than English people could with their own peculiar system. After the first International Exhibition in 1851, so much was said and done about the metric system, that it was almost impossible to elicit a new idea upon the subject. He did not think the arguments that could now be brought forward would enable any one to form a more sound judgment on the matter, than could be arrived at from what had been already exhibited by those who had carefully examined the metric system. If it came to be a question of adopting a form of metric system, he thought that a large majority of engineers would carry the day for it. They were dissatisfied with the present English measures. The difficulties to be encountered, in changing the figures in calculations, represented possible fallacies and inaccuracies, and the greater the number of figures, the greater the number of calculations to be made, thereby increasing the chances of error. He would distinctly express himself in favour of the metric system, or some system which adopted an easy form for calculation, and that the different terms should be called by names that might be readily learned. The thirty-five millions of people in this country, and the Americans, required that names should be given to the different measures, weights, and numbers, and values of money, which they could easily understand and remember, rather than terms and names which would be difficult to learn, and if learned would be soon forgotten.

Mr. Owen. Mr. G. WELLS OWEN observed that it was one of the drawbacks incident to the lot of suffering humanity, a heritage from the days of the Tower of Babel, that people of different nationalities were hampered in their intercourse with each other by differences of language, and, although perhaps not coming so directly from that historical event, by differences of measures, moneys, and weights. Many of those difficulties and differences had been considerably modified of late years, and, perhaps he was not over sanguine in thinking that they would be still more so. The Paper, which tended to a discussion upon one mode of modifying some of those difficulties, was one which he thought the Institution

might very well discuss, because it was more than thirty years since a discussion on a similar subject took place. On the 28th of February, 1854, a Paper by Mr. James Yates was read before the Institution "On the French System of Measures, Weights, and Coins."[1] The discussion upon that Paper related more especially to the matter of the decimal coinage, and, although the consensus of opinion seemed to be in favour of a decimal system, the discussion turned to a great extent upon what was the best standard of value as the basis for that decimal coinage. The part that more particularly interested engineers was that concerning weights and measures, and therefore he would allude no further to the coinage, beyond saying that he hoped that if England ever did adopt a decimal coinage she would disregard all questions as to what the present coins were, and effect a radical change by assimilating it to that of the other countries which were members of the Latin Monetary Union. Those who were accustomed to travel where that league prevailed knew how easy it was to pass backward and forward from one country to another without changing their money, and they also knew what difficulties arose the moment they passed from one of those countries into some neighbouring State unconnected with the Union. No doubt there would be great inconveniences in adopting an entirely different standard of value, but, although that might be so, it was only necessary to consider what had been done, for instance, in Germany, where, at the time of the formation of the German Empire, the numerous coinages that prevailed in the various States were abolished. Former travellers in Germany would probably remember the difficulties they experienced there. He hoped that if England did adopt a new coinage it would be assimilated to the French franc. The more immediate question before the Institution, however, was that of weights and measures, and perhaps it would be interesting in connection with that if he mentioned the dates at which different countries had adopted the metric system of weights and measures, in order to show how it had spread in recent years. In France, metric weights and measures were enacted in 1795, but were not made compulsory till 1840. The metric system, with Dutch names, was introduced into Holland in 1820, but from the 1st of January, 1870, the metric names came in, with facultative use of the old Dutch names. The next country which took the matter up was a very small one at a considerable distance from France—the kingdom of Mr. Owen.

[1] Minutes of Proceedings Inst. C.E. vol. xiii., p. 272.

Mr. Owen. Greece—where metric weights and measures, but with Greek names, were introduced by an ordinance dated the 26th of October, 1836. In 1852, Portugal decreed that the metric basis should be used, and a period of ten years was fixed for its introduction and adoption. The metric measures of length came into use in January 1860, weights in July 1861, surface measures in July 1862, and measures of capacity in January 1863. In Spain the metric system was adopted on the 1st of January, 1859, and became compulsory on the 1st of July, 1868. It was also the legal system of all the Spanish Colonies. In Italy the system was adopted in 1859, when most of the Italian States were united to form the Kingdom of Italy. In the German Empire it came into use in 1872, and in the Austro-Hungarian Empire it was made permissive on the 1st of January, 1873, and compulsory on the 1st of January, 1876. In Switzerland it became the legal system on the 1st of January, 1873; it was adopted in Sweden by an Act of the 19th of May, 1875; and in Norway by an Act of the 22nd of May, 1875, to come into force at the expiration of three years after the passing of the law. In the United States it became permissive by an Act of the 28th of July, 1866. He did not know the date when the system was introduced into Belgium, but it was in use there, and also in the Ionian Islands, Algeria, the United States of Colombia, Peru, Chili, the Argentine Republic, and Uruguay; and it was also permissive in British North America under an Act of 1873. Of course, if the metric system of measures were adopted in England the old systems must be discarded. As the Author had stated, the minds of engineers in America and England were saturated, especially with regard to ironwork, with dimensions expressed in English inches and fractions of inches. That would be a great trouble to English engineers at first, but he thought they must not look so much to what would be a trouble to themselves as to what would be a benefit to the world at large, and no doubt in a short time they would get so familiarized with the new measures, as to use them as readily and freely as they now did the old ones. When the German Empire adopted the metric system of measures, sixteen States fused into that Empire had no less than sixteen different lengths for the foot, varying from 9·84 inches to 12·35 inches. Their other measures varied in a similar manner, but the metric system had been adopted throughout Germany without entailing much inconvenience. All specifications in Germany and Austro-Hungary were now prepared on the metric system, and therefore he thought there would not be much difficulty in getting used to

it in England, where he hoped it would one day or other, perhaps by degrees, be adopted. Mr. Owen.

Mr. Percival Fowler said he had been abroad for some years, and had known many engineers well acquainted with the two systems, but he had never met one who, after a month's practice, did not prefer the decimal metric system. He considered that, with the increasing international communication of the present day, it was of the highest importance that weights, measures, &c., should be uniform in all countries. Scientists had long since recognized the convenience of an international technical language, and in biology, botany, and many other sciences, Latin or Greek names had been chosen which were intelligible to all the civilized world; in electricity the new nomenclature had been adopted by an International Commission. Considering that a uniform decimal system had been adopted in nearly all civilized countries, it was necessary that England should seriously consider the question. English machinery went all over the world, and had to be mounted in other countries by workmen who were not acquainted with eighths, sixteenths, full thirty-seconds, and other like measures. In England the decimal system had been used in many ways. Barometers were graduated in inches and tenths of an inch, level-staffs to feet and tenths of a foot; and in spite of ourselves the decimal system was being introduced into this country. The difficulty of learning the metric system had been immensely overrated. He could speak from practical experience that in Spain, in a week, the workmen became thoroughly conversant with metres, centimetres, and millimetres, and he was certain that the difficulty of changing the English system of weights and measures to the decimal system had been greatly over-estimated. He had heard it said that English weights and measures were more convenient, but he did not see how that could be. He believed that one Ordnance scale was $\frac{1}{25,344}$, and besides the poles, yards, feet and inches, the land measure was 7·92 inches in a link, 100 links in a chain, and 80 chains to a mile. Silver and lead ores were reckoned by so many ounces troy to 1 ton avoirdupois, so that in order to arrive at the proportion of silver in lead it was necessary to take two separate measures, and calculate them. With regard to the question of calculations for water, since a litre of water weighed a kilogram, the calculation was of the simplest sort. In England the measurement was effected in cubic feet or gallons, and he always had to refer to a book of tables, for he could never remember the equivalent figures. A most inconvenient scale was three-sixteenths of Mr. Fowler.

Mr. Fowler. an inch to a foot, and a calculation had to be made as to what proportion that was. He did not understand why it was that Englishmen had not yet adopted the decimal system. The French proverb might be true, "Les Français inventent, mais les Anglais perfectionnent," but as regarded the decimal system, Englishmen had neither invented nor improved it, and he thought they ought to adopt what had been found practicable in nearly all civilized countries. It would be of the greatest convenience, as he did not believe that a single member of the Institution had not constantly to refer to a table of that extraordinary medley English weights and measures.

Mr. De Salis. Mr. Rodolph De Salis desired to mention a few facts which he thought told in favour of the present systems. It could not be denied that starting with a clean slate a universal system of weights, measures, and coinage would be desirable; but it might be fairly questioned whether a decimal system would be the best, and if a decimal system were adopted, whether it should be based on the metre; and as different systems were in existence, it might also be questioned whether the advantages of a change would counterbalance the disadvantages. In considering such a change, the advantages should be gauged not by the preferences of scientific persons, but by the convenience of the bulk of the people; and he certainly thought, for general purposes, a system admitting of binary and ternary subdivisions was more convenient than a system based on decimal subdivisions. All knew the convenience of dividing anything into halves, quarters, or thirds, or their subdivisions. It was not so clear how conveniently to divide things into fifths, tenths, and hundredths in the ordinary practical affairs of life. Of course, for all purposes of calculation a decimal system had immense advantages; but, practically, that system was in use in all calculations. Everything was decimalized, or was worked by logarithms. Even actuarial computations were always made in sovereigns and decimals of sovereigns; indeed, under the present system, computers had the advantage of using decimals when they liked, and fractions when they were most convenient. The present measures, he thought, were very convenient. A yard, for example, was the $\frac{1}{1,760}$th of a mile, and the $\frac{1}{4,840}$th of an acre. Then there was the ternary division of the yard, the foot. He had always considered the foot to be a particularly handy measure for hydraulic and other calculations. It correlated very well with the gallon and the pound, 25 quarter gallons or 50 pints making a cubic foot—near enough for all practical purposes—and

10 lbs. of water a gallon. With regard to the practical uses of the foot, the only instance he would give was that of building, and the cognate trade of brickmaking. A brick was $\frac{3}{4}$ by $\frac{1}{4}$ of a foot, and its breadth was its length divided binarily. Those were convenient fractions, and from them quantities could be estimated. The thickness of a wall was one brick, a brick and a half or two bricks, and it contained so many courses of brick-work, all in terms of the foot. If the metric system were adopted instead, it would be found that a brick was equal to 0·2286 by 0·0762 by 0·1143 of a metre, which he did not think would be very convenient. But if the brick were to be changed to suit the new system, the inconvenience would be very great; all contracts for the sale of brick earth would have to be revised, and brick-making machinery would become antiquated. Again, it would be a great disadvantage that new work could not be conveniently joined to old work. The old bricks could not be used with the bricks of the new standard. How could old work be bonded on to new? It would be almost sure to result in failure. With regard to the theoretical basis, he agreed with the Author that the accuracy or otherwise of its relation to the meridian was not material; but according to Sir John Herschel,[1] the inch was as scientific a basis as the metre. Again, the yard was an extremely convenient step, and on that account a good basis. It was a better step than the metre. It was a natural step for a tall man, and a very long step for a short man; but adding 3·37 inches for each step would probably put it beyond the compass of a short man, and he could state personally that it was a longish step for a tall man. That was a practical consideration which ought not to be disregarded. What were the advantages to be gained by the adoption of a change which would certainly affect nearly every transaction in life? A map (Plate 1) had been exhibited showing the size of the countries using metric measures as compared with the British islands, and on the theory that the smaller must yield to the greater, it was urged that the metric system should be adopted in England. That argument, if worth anything, operated entirely the other way. The British sway extended over one-fifth of the habitable globe, while the area of metric countries was only about one-thirty-fifth. The British empire included a population of 310 millions, the United States 50 millions, and the metric countries about 200 millions. The British imports

Mr. De Salis

[1] "The yard, the pendulum, and the metre, considered in reference to the choice of a standard of length." 1863.

Mr. De Salis. and exports for 1883 to the British possessions amounted to £188,000,000, to the United States to £135,000,000, to various other places to £142,000,000, making a total of £465,000,000; the amount to the metric countries was £266,000,000. Therefore, as far as size went, the balance was entirely on the side of the present measures. The coinage would certainly be more conveniently affected by a change than weights and measures; but he thought the commercial classes were not in favour of change. In 1849 the florin, the decimal subdivision of a pound, was introduced, and the coinage of half-crowns was stopped. In 1874, a circular was addressed to bankers and others interested, asking whether half-crowns should be discontinued or florins, or whether both should be coined. In official phraseology the answer to the circular showed an "overwhelming preponderance" in favour of the continuance of both coins, while out of six letters to "The Times" on the subject, not one advocated the dropping of the half-crown. He did not regard with the Author's equanimity the depreciation in the value of their library which would result from a change in notation. No doubt a certain number of text-books would be translated, but the bulk of the works, all the Parliamentary papers, books of reference, and, he should imagine, nineteen-twentieths of the library would become antiquated and practically unusable; whereas under the present system it was found that any good book published in French or German was promptly translated into English with English measures, and took its place beside English literature. It had been urged that the metric or decimal system was much easier to learn. No doubt it was, but surely that was not altogether an advantage. He would put it in the form of a proportion sum: As Greek is to French so is the English complicated system to the metric system in point of mental training. He dissented altogether from the idea that the professional classes should be the first to advocate a change of that sort. Such a change ought to come from the bottom and not from the top, and ought to be the product of necessity. That the bulk of the people did not feel the need of the change was, he thought, shown by the fact stated by the Author, that the general public in both countries, England and the United States of America, appeared indifferent on the subject. As professed mathematicians, or at least arithmeticians, he thought engineers ought to be ready to adapt themselves to any system that appeared to commend itself to their clients, and not expect them to give up convenient binary divisions in order to facilitate professional calculations. He classed a universal system of

measures, weights, and money in the same category with a universal language. Both were theoretically very advisable, but he thought they were not practicable. No doubt they would be much less anomalous than the present system, but he doubted whether they would be so useful. Mr. De Salis.

Mr. R. C. Rapier said that ten years ago he should have made much the same speech as that which had just been delivered. In 1868, when the great discussion on the subject took place, he was strongly in favour of retaining things as they were; he then thought there was no measure of length so convenient as the English foot, and no unit of capacity so useful as the English gallon. But circumstances altered cases. During the last fifteen years he had been obliged to have recourse to metres, kilometres, and such like measures, and he found that they were not so objectionable after all; in fact, he had compiled some useful and handy rules for himself on the subject. Mr. De Salis had spoken of the importance of conserving the English system. Mr. Rapier ventured to say that the English weights and measures were not a system, they were an accident; they were never created upon any systematic principle or plan. In one part of the country 14 lbs. were a stone, and in another 16 lbs., and similar diversities were well known. Whether the standard of length was a pendulum vibrating seconds, or the common yard or foot, he did not care; but he maintained that a decimal system was the right one, and he inclined strongly to the metric system, because it was already established over the rest of Europe. The metric system had the advantage of an intelligible and definite connection between units of length, units of capacity, and units of weight. The metre was referable to the vibration of a pendulum; so would any other unit be, but it so happened that the cubic metre coincided very nearly with the English ton, the French tonne. He thought encouragement might be taken from the fact of that connection. With regard to money, the present system on the plan shadowed forth by the Author, and previously mentioned by Sir John Herschel, admitted readily of an adaptation to a decimal system, and it had a tolerably near affinity to the system on the Continent, bearing in mind that twenty English shillings were as good as twenty-five francs. The convenience of the relationship of the measures on the metric system was very great. For instance, a cubic metre of water was a ton. The number of cubic metres of any other material multiplied by its specific gravity gave the number of tons. Again, to take a familiar illustration, that of a railway to be laid with rails 35 kilo- Mr. Rapier.

Mr. Rapier. grams per metre, there were 70 metric tons in a kilometer; it was easy to reckon how many English tons there would be according to the English system, but in the other case it was obvious. If the members would regard the matter practically for about six months, they would begin to think in the new measures, and then the whole would become perfectly easy. To facilitate thinking in metric measures he had adopted the following ready rules: To convert metres into feet divide by 3, and move the decimal point one place to the right. To convert feet into metres, multiply by 3, and move the decimal point one place to the left. To convert millimetres into inches, multiply by 4, and move the decimal point one place to the right. To convert inches into millimetres, divide by 4, and move the decimal point one place to the left. To change hectares into acres, divide by 4, and move the decimal point one place to the right. To convert square metres into square yards, add one-fifth. To change cubic metres into cubic yards, add one-third. To convert kilometres into miles, divide by 2, and add one-fourth. All the above examples were worked by the use of the elementary numbers 3, 4 and 5, and gave results correct within 1½ per cent., and the rules were therefore sufficiently near for the purpose of mental calculation to facilitate a familiarity with the metric equivalents.

Mr. Young. Mr. E. W. Young, to show the comparison between decimals and duodecimals, exhibited a calculation in compound addition by both methods, in which there was one column more in the decimal sum than in the duodecimal. Again, to illustrate the ordinary transactions in commerce, millions of which took place every day in London alone, suppose a shopman wished to ascertain the cost of 17 yards at 5¾*d.*, he did not reduce 5¾*d.* to farthings, multiply by 17, and reduce back to pence and shillings, but he applied a process of mental arithmetic, thus: he said, Why, that is 17 sixpences less 17 farthings, or 8*s.* 6*d.* less 4¼*d.*, that is 8*s.* 1¾*d.* It was done in an instant. Now if the decimal system were in force, and there were 25 farthings to the sixpence, the shopman would have to multiply yards by farthings, which would be far less convenient than the present system. Indeed for every little purchase made, the shopman would have to pull out pencil and paper to make a calculation. The duodecimal system had the advantage over the decimal system in admitting the use of fractions to a much greater extent, so that sums could be more easily done mentally. It was not the convenience of the scientific or professional man in his office that ought to be considered, but the general convenience of the multitude in the millions of transactions going on throughout

the country. The introduction of the metre would necessarily Mr. Young. mean the introduction of the decimal system generally, and he thought that an alteration to the decimal system would occasion very great inconvenience, and it was exceedingly doubtful whether there would be any economy of labour in it. For the purpose of contrasting the metre with the present British standards of measurement, the following example afforded a fair comparison between the two systems. The sum was: required the contents in cubic yards of a block of masonry 88 feet by 3 feet 9 inches by 2 feet 3 inches. The usual way of doing this was by fractions, thus, $\frac{88^y}{3} \times 1\frac{1}{4}^y \times \frac{3}{4}^y$. The threes cancelled one another, and the result was at once $\frac{110}{4}$ cubic yards = 27·5 cubic yards. Using the decimal system, it would be necessary first to multiply 88 by 3·75, and the product by 2·25, involving a large number of figures. Even then the result would only be in cubic feet, and though it would be unfair to the decimal system to debit it with the figures that would be needed to reduce cubic feet to cubic yards, the sum so done would be a better comparison of the two systems than the example given by the Author, which he thought ingeniously unfair. With regard to the suggestion that twenty-five farthings would equal sixpence; that, he thought, would be a great disaster, because 24 could be divided by 2, 4, 8, 12, 6, and 3, and those numbers were again divisible by others. Altogether there were eighteen divisions and subdivisions, but 25 could only be divided once by 5. He did not know how it was that the present duodecimal system was first hit upon. Evidently those who made 12 inches to the foot had some idea of utility. The same system was constantly used. There were twenty-four hours to the day; the arc was divided into 360°, a multiple of twelve. He had heard, however, that an agitation was going on for a division of the circle into decimals, which he should very much regret. If that were accomplished he supposed there would be a demand for twenty hours to the day instead of twenty-four. There was a disadvantage in the decimal system in consequence of the similarity of some of the terms, such as decimetre and decametre, decilitre and decalitre, deciare and decare, decistere and decastere. He believed that working men would be confused with words so much alike, and a great many mistakes would be made through bad writing. If a man forgot to dot the "i" that might make all the difference between a decimetre and a decametre. He thought it would be a good thing to get rid of the 66-feet chain.

Mr. Young. There were many anomalies in the present system, and a great many things that it might be desirable to change; but it was a serious matter to propose to change the whole of the system adopted in England, in the Colonies, and in the United States. He considered it a mistake to lay so much stress upon foreign commerce. No doubt it was large, but it was small in comparison with the internal commerce of the country. Foreign commerce, too, was wholesale, while internal commerce was chiefly retail; so that there might be ten thousand or one hundred thousand transactions taking place in this country with the present system of coinage and measures for one negotiation in metres. When Englishmen went abroad they took French money with them, and knew how to deal with it, and on returning home they had no difficulty in reverting to their own system. It might be necessary for German duchies about the size of an English county, placed between two large states like France and Germany, to adopt the metric system, but not a country like England.

Mr. Cowper. Mr. C. E. Cowper wished to call attention to three points. With reference to the calculation submitted by the Author, some of the advocates of the British system had computed it in different ways, some by duodecimals and some by vulgar fractions. The Author had brought it forward as a sample calculation to show the superior advantage of the metric system, but he did not think he had done his best; because, though the tank might have been marked on the drawing 10 feet 6 inches, its dimensions would be, perhaps, when made, $\frac{3}{8}$ inch more or less than that length. What was a tank to be measured for? If he had to measure the tank to find the weight of the water, in order to ascertain what sized injector to put in, or what size of feed-pump to use for a boiler, he would be content to take it approximately—say, 2 tons, which would be near enough. Suppose, on the other hand, great accuracy were needed—if, for example, the tank were used for gauging water in a pumping-engine trial, measuring the feed-water into the boiler, (and the contract price might depend upon the economy,) the case would be very different. In that case the dimensions of the tank might be 10 feet $6\frac{3}{8}$ inches by 6 feet $2\frac{5}{8}$ inches; and the depth of the water, perhaps, 1 foot $\frac{3}{16}$ inch. He thought the duodecimal system, or the vulgar-fraction system, would not then work out so neatly; but by the metric system it did not matter whether the measurement was 0·33, 0·34, or 0·35; the calculation was not any longer. Again, the Author might, he thought, have made more of the smallness of the unit. Regarding the question as a matter of abstract principle, suppose it were

necessary to make an arrangement for a new world, where no difficulties would arise on account of established customs or international intercourse, a small unit of measurement, convenient to work to, and one that could be easily divided on boxwood or steel, would certainly be looked for. Such a unit existed in the millimetre, but not in the inch, or any decimal division of the inch or foot; the tenth of an inch was too large and the one-hundredth too small. The millimetre was as small as required for any practical purposes, and it could be subdivided microscopically to any extent. Reference had been made to the use of logarithms; but he wished now to direct attention to the mechanical use of logarithms, to which, he contended, the metric system lent itself. He might raise a smile if he referred to the slide-rule, because people generally thought of the dirty, black, greasy thing which the fitter carried in his pocket and did not know how to use; the slide-rule there was in the wrong place; the fitter did not want it, and the proper place for it was in the office. It was little used in England, and one of the reasons for that was the complicated English system, or combination of systems, of weights and measures. In France, one of the improved forms of the slide-rule was found, he had been informed, on almost every engineer's desk; in electrical engineering it was very largely employed. Two of the largest electrical establishments in England used one or other form of the slide-rule, or the logarithm-slide, to a great extent. He therefore claimed that the metric system being a decimal system, which allowed every calculation to be checked readily by the slide-rule, possessed a substantial advantage. Many persons thought this instrument a trivial affair; but only a practical acquaintance with it would enable them to form a sound judgment as to its merits. Mr. Cowper.

Mr. H. J. Chaney thought it was desirable, in order to facilitate discussion, to separate the question of weights and measures from that of money. The money aspect was no doubt very interesting, but experience had shown that the question of the introduction of a new system of weights and measures could be best considered by itself. The subject under discussion was not that of decimalizing weights and measures, or introducing a decimal system of money, but the desirability of introducing the metric system which was not only decimal, but binary. He supposed that few persons who had much acquaintance with the present system of weights and measures could admit it to be the best that could be provided. The metric system, *per se*, was by far the most convenient; but then the inconvenience of making a Mr. Chaney.

Mr. Chaney. change which would so largely affect the daily transactions of life had to be considered. The discussion, he thought, should deal with the difficulties in the way of such a change. The question of the comparative advantages of the metric and British Imperial systems had been well thrashed out. Reference had been made to the Standing Orders requiring that all scales should be according to Imperial measure, as 4 inches to the mile, and he would suggest for consideration the nearest form of metric equivalent. Besides 4 inches to the mile, the Standing Orders might also permit a scale of 65 millimetres to the kilometre. Buildings, also, were to be drawn to an enlarged scale, of not less than ¼ inch to every 100 feet; for that scale there might also be permitted a scale of 7 millimetres to every 30 metres. Sections might be given to a scale of 1 millimetre in every 1,200 millimetres, or in every 12 decimetres, as well as to a scale of 1 inch to every 100 feet. Quantities might be allowed to be given in metres and parts of a metre, as well as in yards, feet, decimal parts of a foot, and inches. Distances might be permitted to be expressed in kilometres and metres, as well as in miles, furlongs, chains, poles, yards, and feet.

Mr. Walton Williams. Mr. W. WALTON WILLIAMS said he did not think it was necessary to choose immediately between the two systems. Engineers, before tying themselves down to the metric system, ought to consider whether it could be in any way improved. According to French engineers the metric system was absolute perfection, and Englishmen were a set of idiots for not adopting it. He had been obliged to use the metric system for many years abroad, and he desired to point out two or three disadvantages connected with it, in the hope that they might be remedied. No man could step a long distance in metres. He had seen French engineers try to do so; they could step 100 metres, but, if the distance was 400 or 500 metres, they would reckon every step to be 90 centimetres, equivalent to the English yard. The Author had stated that the metre was the right length for a measure, but Mr. Williams contended that no man could measure with it easily. The eye subtended an angle of 60°, so that a man's arms ought to be a metre long to be able to see both ends of the metre rule. The Author had stated that a workman could measure with a metre rule in two-thirds of the time required with a two-foot rule. That he denied from his experience of foreign workmen, who with a metre measure were generally longer and less accurate measuring than Englishmen with a two-foot rule; besides which the foreigner generally called in another workman to put a mark at the end.

Mr. Walton Williams.

The French themselves did not admit that the metre was absolutely the best unit of length, for any one going into a draper's shop would find that a half-metre and not a metre measure was generally used; the demi-kilo was frequently used for weight, and the customer might be heard asking for "Le quart d'un demi-kilo." With reference to levelling, it did not make much difference theoretically whether engineers divided a foot or a metre by the decimal system, except that they could frequently see the foot mark on a staff, when they could not see the metre mark. He had known instances in which a mistake had been made of a whole metre, because a man would not, or did not, lift up the staff the required distance. If a French staff with a disk were used it would be different, but where the staffman moved the disk up and down it had to be brought each time to be verified, so that the time was doubled. With regard to drawings, if they were made to a scale of $\frac{1}{10.000}$, $\frac{1}{5.000}$, or even $\frac{1}{1.000}$, it did not matter whether feet or metres were used. In drawing to a larger scale, 1 inch to the foot, the English $\frac{1}{12}$ corresponded to the French $\frac{1}{10}$; but to vary it the Englishman could go from 1 inch to $1\frac{1}{2}$ inch, or to $\frac{3}{4}$ of an inch, while the Frenchman would have to go up to $\frac{1}{5}$ or down to $\frac{1}{20}$. It had been said that $\frac{3}{16}$ of an inch was an absurd scale. Possibly; but it was $\frac{1}{64}$ of a foot; and 64 was 2 multiplied by itself five times. To put $\frac{1}{64}$ of a metre into decimals, six places of decimals would be required. He did not say that engineers ought not to adopt the metric system, but they should not be absolutely tied down to it as it at present existed. It was their duty to improve it if possible according to the saying already quoted: "Les Français inventent, mais les Anglais perfectionnent." He wished to address a few words to those who were in the habit of preparing drawings for foreign works. He had had many such drawings sent out from England, and they had been usually drawn to an English scale, and the dimensions inserted in metres. When a Spanish stonemason, or an Italian carpenter saw such drawings he was puzzled, and fresh ones had to be prepared for his use. To those who were in the habit of using the 1-inch or $1\frac{1}{2}$-inch scale $\frac{1}{10}$ was not convenient, but he thought that, considering the immense number of drawings going abroad for foreign work, a little sacrifice ought to be made in order to adapt them to the metric system, even if that system were not generally adopted in this country.

Mr. Thelwall.

Mr. W. H. Thelwall remarked that he had used both the metric and the English systems for nearly twenty years, and although he was not frightened at the metric system, he was

Mr. Thelwall. decidedly of opinion that the English was much more convenient in all matters of civil engineering. The Author had not given any statement of the relative times taken to do various works. He had said that a French workman could measure planks in two-thirds of the time occupied by an English workman, but if that statement was to be of any value, it ought to be supported by actual experiment. He fully agreed with what had been urged by Mr. Walton Williams that the metre was inconveniently long for accurate measurement. The Author's statement with regard to levelling was much too vague to be of any practical value, since it contained no account of the time saved. According to his own experience, French engineers were not satisfied with working to centimetres, but, even in trial sections over rough ground, worked to millimetres. In the case of sections of railways the ground and formation-levels, and the heights and depths of cuttings and banks, had been all worked out to millimetres, requiring three places of decimals instead of two, which was a serious matter. Referring all measures to the metre involved the use of a much larger number of figures than the English system. He had copied some dimensions, that he had recently met with in a French publication, of a tramway locomotive. The diameter of the cylinder was 0·220 m.; in English measure it would be 9 inches: the stroke of the piston was 0·350 m.; in English it would be 14 inches: the weight, empty, was 11,000 kilograms; in English, 11 tons: the weight, running, 13,000 kilograms; in English, 13 tons: the heating surface 18·90 square metres; in English, 203 square feet. Thus there were twenty-two figures in French, and only ten in English, measure. Take another instance, that of the strains and weight of a wrought-iron pillar, having a load of 25 square metres of flooring weighing 6,600 kilograms per square metre. $25 \times 6{,}600 = 165{,}000$ kilograms. The area of the pillar was

Web	450×12	$= 5{,}400$	square millimetres.	
4 plates . . .	500×12	$= 24{,}000$	"	"
4 angles . . .	$\dfrac{100 \times 100}{12}$	$= 9{,}000$	"	"
4 " . . .	$\dfrac{80 \times 80}{10}$	$= 6{,}000$	"	"
Total		44,000	"	"

$$\text{Load per square millimetre } \frac{165{,}000}{44{,}000} = 3 \cdot 7 \text{ kilograms.}$$

In English measures the above would be, load of 270 square feet

of flooring weighing 0·6 ton per square foot = 270 × 0·6 = 162 tons. The area of the pillar would be Mr. Thelwall.

	Inches.		Inches.		Inch.		Square Inches.
Web	18	×	$\frac{1}{2}$			=	9
4 plates	19	×	$\frac{1}{2}$			=	38
4 angles	4	×	4	×	$\frac{1}{2}$	=	15
4 ,, ...	3	×	3	×	$\frac{3}{8}$	=	8
			Total				70

$$\text{Load per square inch } \frac{162}{70} = 2\cdot32 \text{ tons.}$$

Such examples might be multiplied indefinitely. They had not been made up for the purpose of showing comparisons unfavourable to the metric system, but were fair samples taken at random from actual French practice, and converted into the corresponding English figures. Again, such things as diameters of pipes were measured by 200 millimetres, 150 millimetres, and so on, the English equivalent for which would be 8 inches and 6 inches. It frequently happened that, in the French system, three figures were used instead of one; and when in taking out quantities the figures had to be multiplied, the difference was very serious. If the Author really considered that there was a saving of time by the metric system, he ought to have given an example such as an estimate of work, or the calculations and quantities in a large iron bridge properly worked out by both the metric and the English systems, and not the long sum in the Appendix, which could be computed with less than half the number of figures given. He was convinced that the more acquaintance English engineers had with the practical working of the metric system, the less disposed they would be to exchange their own for it.

Mr. W. Airy thought that the Author had somewhat mixed up two very different matters, the metrical unit and the decimal system, which ought to be kept distinct. It appeared to him that the best unit was that which the experience of people had decided to be the best for the greatest number of measurements. For the great bulk of measurements—those relating to building, construction, and manufactures generally—the metre could not be used without subdivision, and it was therefore, in his opinion, wholly unfit for the unit for such measurements. That was proved by the fact that, in England, where the people had the choice both of the yard and the foot—and the yard for that purpose might be considered as comparable with the metre—for the great bulk of their measurements they used the foot, and not the yard. He thought it would hardly be denied that the foot was the real unit Mr. Airy.

Mr. Airy. of the English people. The metre was much too long a unit for the ordinary affairs of life; and even in France, the head-quarters of the metre, there were cases in which the French still used the foot. In Sweden and Norway also, as well as in other countries professing to use the metric system, the foot was employed for a variety of purposes. He thought there could be no doubt that the decimal subdivision of the unit, whatever it might be, afforded great facilities for calculation; and therefore for all those measures, or classes of measures, which involved frequent or complex calculations, great advantages would be derived from the adoption of that method. It would, for example, be a great advantage to subdivide the foot into 10 inches, and the inches into tenths, and he thought that such a change would be acceptable to the country at large; but for all measures referring to articles of consumption, he believed the binary system, which was much more simple to uneducated people than the decimal system, had a firm hold upon the people, which it would be impossible to shake. The Author would have done well to have made some mention of the case of Russia, which, long after the metric system was fairly established in central Europe, had occasion to set her standards in order, and after due consideration had adopted the English foot as the unit, altering the national measures so as to form exact multiples of it.

Mr. Hanson. Mr. E. B. HANSON said he thought that the sum, given in the duodecimal system, ought to have been worked by duodecimals and not by decimals. In answer to Mr. Airy, it would be sufficient to say that the standard yard was divided into feet, of which 1 foot was divided into 12 inches, and so the foot formed part of the standard. The Author had found fault with engineers for measuring with a two-foot rule, and afterwards asked them to measure with a 20-metre chain, which was hardly consistent. He then spoke of "five-sixteenths full," or "bare three-eighths," as if they were the same thing. Mr. Hanson had always understood that if there was a hole of exactly three-eighths diameter, the cylinder which would fit into it would be a "bare three-eighths," and *vice versâ*. He did not think that any brickwork or any engineering work was measured in rods now: he believed it was always measured in cubic yards. A scale $\frac{3}{16}$ inch to a foot was, he believed, one of the best. It came near to 5 feet to the inch, and it had the advantage that it was a fractional part of $1\frac{1}{2}$ inch to the foot, which was so useful a scale to the carpenter, inasmuch as $\frac{1}{8}$ inch on his rule represented an inch. Ordinary working plans for railways and so on were plotted

Mr. Hanson.

with the horizontal scale 2 chains, and the vertical scale 20 feet to an inch respectively. There was not the slightest difficulty in passing from one to the other. The same scale did for both, whereas with the metric system two scales would be necessary to measure by, and there would be a constant changing. If parliamentary deposited plans were plotted in metres, farmers and others would be wanting to know how many square metres there were in an acre. They did not reckon by metres, and it would take years to make them do so. When he was in Paris during the Exhibition of 1878, he went with a brother engineer to visit some shops where several young artizans were being taught under the French Government, and he was much astonished to find that they were using the two-foot rule, and also using English names for the various tools. On asking the reason he was told that it was found to be so much more convenient. In some shops in England, where a large number of Germans were employed, machines had been constructed partly in millimetres and partly in inches. Pulleys and things of that sort were generally measured in inches, and the smaller parts in millimetres. Considering that the metre was introduced into France forty-five years before it was properly legalized, before railways were made, and before engineering works assumed their present importance, the time it would take to introduce it into England now could hardly be estimated. There were certain standards in England which might be considered as hard and fast. The railway gauge was one of them, and it could never be altered. The measurement of 4 feet 8½ inches looked well enough as it was, but in the new system it would be 1·435 m. There was also a standard measurement of bricks. If the metric system were introduced, he supposed that bricks would be made ¼ metre long. A trial had been made of bricks 10 inches by 5 inches by 3 inches, but they had not succeeded, and he believed the use of them had ceased.

Mr. Vernon-Harcourt.

Mr. L. F. Vernon-Harcourt said there could be no doubt that scientifically the metric system, in which the weights and measures were connected, and arranged according to a definite plan, was better than the English; but there were some disadvantages in it which ought not to be over-looked. The metre, being a larger unit than a foot, required more subdivision to measure small dimensions, and was less well adapted for levelling than feet and decimals of a foot. The constant use of decimals, moreover, in the metric system, led to the abandonment of fractions and proportions, which had a distinct value of their own in certain cases. Errors, for instance, were more liable to occur when gradients were

Mr. Vernon-Harcourt. expressed in decimals, such as 0·00125 and 0·000333, instead of as 1 in 800 and 1 in 3,000; and $\frac{3}{16}$ and $\frac{1}{60,000}$, were simpler modes of expressing these proportions than 0·1875 and 0·000016̇. In a string of noughts after the decimal point, one of them was very liable to be omitted, or the decimal point itself might be readily misplaced, causing in either case a tenfold error. Also fractions were expressed more shortly in words, and were consequently more easily remembered and repeated than decimals, where each digit had to be separately named; and the use of commas for marking off the thousands, which greatly facilitated the reading of figures, could not be employed for decimals. The Author had stated that scales for drawings were much better represented by the French than by the English system, and Mr. Vernon-Harcourt had therefore taken the trouble of looking out a few scales given in some French engineering works, of which the following were instances of those occasionally adopted; namely, 0·06667 m. per kilometre, 0·00143 m. per metre, 0·004165 m. per 100 metres, 0·0104 m. per metre, and 0·0278 m. per kilometre. Those figures, he thought, would be sufficient to show that the French scales were not always so simple as some persons imagined. No doubt a reform might be introduced, and it would be a great advantage in all engineering literature to have scales that would be comparable. He had himself tried to introduce such scales in the form of definite simple fractions of the natural size. In the illustrations for a book very shortly to be published[1] he had managed to make two hundred and twenty-five figures to nine scales, all of these scales being multiples, or parts of one another, ranging between one-thirty-thousandth and one-hundredth of the full size; so that it was possible to compare the various plans together. As to the statement with reference to calculations, he felt sure that any one who had worked with Bidder's tables for getting out earthwork could do so more quickly that way than by any other method. The Author had stated that in the case of English measurements, bushels, and cubic yards were used. When inspecting works in France he had frequently asked for the proportions of cement or lime employed in concrete or mortar, and he was always told that there were so many kilos to the cubic metre; so that in that respect there was not much advantage in the French system over the English. If the new system were adopted in parliamentary plans, especially if some plans were figured in metres and others in the ordinary English dimensions, both witnesses and the legal

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[1] "Harbours and Docks," by L. F. Vernon-Harcourt, vol. ii., plates.

profession would be much puzzled. It was questionable whether the advantage in consulting foreign books, that would accrue from the adoption of the metric system, would for a long time counterbalance the loss resulting from the different notation of the whole existing British and American engineering literature. Much of this literature, including the eighty volumes of Minutes of Proceedings of the Institution, could not be reproduced with metric measures; and the necessary alterations in the Ordnance survey and the Admiralty charts would involve a large expenditure. If the metric system were introduced it would simplify calculations; but, in making the change, it would be necessary to take into account all the English-speaking communities, and a conference would be required in order to arrive at a consensus of opinion. A common system of weights and measures would be of very great value. The discussion, however, had indicated that much could be urged on both sides of the question; and unless the balance of advantage proved greatly in favour of the change, the present generation could hardly be forced to incur great inconvenience for the possible benefit of posterity. The change, if made, should be gradual, with the concurrent use for some time of both systems, and aided by elaborate conversion tables. Moreover, in such a matter, Great Britain could not be regarded merely as a European power, and the metric system would have to be adopted also simultaneously by the Colonies and the United States if any real benefit was to be gained. Mr. Vernon-Harcourt.

Mr. J. W. Barry agreed with Mr. Airy that the metre was far too large a unit for practical work. Some portion of his early life having been passed in measuring up work with quantity-surveyors, he could bear out the statement that in no case was the yard used as the unit of measurement, and in the case even of large dimensions, the foot was universally employed. He could by no means adopt the recommendation of Mr. Airy that the foot should be divided into ten parts. It was a very great advantage that it was divided into twelve parts. Any one who had had much practical work would know the advantage of being able to divide the foot by two, three, four, and six. The decimal system was comparatively useless to a man who had to work with his hands, or for mental calculations, and, moreover, absolute correctness could not in many cases be obtained by it. By the duodecimal system absolute correctness could always be obtained. Very often a measurement was required which had, perhaps, to be afterwards multiplied many hundreds of times, and if there was a small Mr Barry.

Mr. Barry. fraction wrong in the original measurement it might result in a serious error. The change from the duodecimal to a decimal system would, in his opinion, be a retrograde movement. He thought nothing was to be gained by discarding duodecimals, and would say, in the words of Lord Melbourne, "Why cannot you let it alone?"

Mr. Preece. Mr. W. H. PREECE said he happened to be a member of the Committee of the British Association which had succeeded in establishing a system of electrical units based on the metrical system, and that system was now in use by every nation throughout the world, so that electricians in every country could speak amongst themselves in a language understood by all. There was not a labourer in any electrical engineering establishment who did not speak in accordance with a metric system which was completely understood. The advantages of the metric system were not to be met by ridicule. It would be an easy thing to turn the British system into ridicule. It might be said, for example, that Englishmen were so consistent that they measured the depth of the ocean by fathoms, and the height of mountains by feet; they measured their own height by feet, and the height of their horses by hands; they measured the surface of the land in miles of 1,760 yards, and the surface of the sea in miles of 2,025 yards; ale and beer were measured by barrels, kilderkins, hogsheads, pipes, and the like; they weighed their fuel in chaldrons, tons, or loads, according, as they used coke, coal, or wood; then there was Troy weight, avoirdupois, and apothecaries weight, with scruples, ounces, pounds, and so on. But ridicule would not convert any one. The only valid objection raised to the decimal system was that it could not be divided by one-third. For two years he had been trying to find out any circumstances that had necessitated his dividing by one-third, and the only thing that had come under his notice was the bill of his lawyer, who divided the pound by one-third, and charged 6*s*. 8*d*. It had been stated that the metric system was invented by the French; but with reference to the decimal system, it was worth knowing that on the 14th of November, 1783, before the system was proposed in France, James Watt wrote a letter to Mr. Kirwan, in which he fully developed a decimal system based upon the pound.[1] He agreed with previous speakers that the decimal system and the metric system should be kept separate. The metric system was a system of measurements

[1] "The Origin and Progress of the Mechanical Inventions of James Watt," by J. P. Muirhead, vol. ii., p. 179.

based on uniformity and simplicity, a system that would bring the whole civilized world together under one roof, and enable men to speak to each other in one language. He did not like to prophecy, but he thought the time was not far distant when the engineering profession would, like one of its branches, the electrical, seize upon the decimal and metric system as a labour-saving machine. It was a mistake to say that the metric system was not a binary system; it was essentially a binary system. Reference had been made by other speakers to the use in France of half a kilogram and half a millimetre. All men reasoned by experience. The man who had been accustomed all his life to the one-foot rule could not understand the metre, just as the man who had been used to the metre could not understand the one-foot rule. The English system had the merit of being ancient. It was established in 1266 by Henry III., who ordered that for the future 1 dwt. should be thirty-two grains of wheat, and that 20 dwt. should be 1 oz., and 12 oz. 1 lb. Edward II., in 1324, ordered that three barleycorns should be 1 inch, and 12 inches 1 foot. The British system, therefore, rested upon the scientific basis of the weight of a grain of wheat and the dimensions of a barleycorn. Mr. Preece.

Mr. Hamilton-Smythe.

Mr. HAMILTON-SMYTHE, in reply upon the discussion, said he regretted that criticisms of the particular calculation in metric, and in decimalized British measures which he had, perhaps somewhat unadvisedly, selected, appeared to have diverted a good deal of attention from the broader question of the general comparative merits of British and metric measures for engineering purposes. By ingenious sleights of mind, when calculating British measures by vulgar fractions, and by great proficiency in mental arithmetic, some English engineers were able to evolve results in engineering calculations which excited the admiration of simpler arithmeticians. The capacity for such feats had no doubt been fostered, as was suggested by Mr. De Salis, by long practice and experience in battling with the complexities of British measures; and the difficulties which English boys had to contend with in learning British arithmetic and mensuration had, in many cases, developed mathematical capacities similar to those literary capacities which were supposed to have been developed by long and arduous studies of ancient Greek literature. Literary men, however, were able to escape from the Greek particles and irregular verbs after leaving a school or college; whereas, British engineers could never evade the wholesome discipline of those rather irksome educators, the com-

Mr. Hamilton-Smythe. pound rules of arithmetic and the British tables of weights and measures. It had once been urged that the introduction of machinery would destroy the individual capacity of the handicraftsman. Possibly this had been the case, yet the general result of the introduction of labour-saving machinery could hardly be alleged to have been unsatisfactory, and it might be asked whether the time now devoted to mastering the complexities of British arithmetic and mensuration might not be more usefully employed in overcoming technical difficulties, the study of which might develop equal mental capacities with more directly remunerative results. As time went on, and England became more fully equipped with engineering works, British engineers would probably find themselves more dependent on foreign work, and brought more into competition with foreign engineers in securing it. A considerable portion of this work would lie in countries using the metric system, so that familiarity with the system which, to quote Mr. De Salis, "appeared to commend itself to their clients," would probably be of ever-increasing importance to British engineers; while, if they were always to be burdening their memories with a double set of standard engineering dimensions and quantities, for use alternately at home and abroad, they would carry a load that would handicap the brains of most in the race for foreign work. If engineers wanted to get the full advantage out of a system of measures, they must accustom themselves to think in it. Mr. De Salis had deprecated any alteration in the size of the brick generally used in England; but bricks measuring 22 centimetres by 11 centimetres by 7·5 centimetres, would probably bond in sufficiently well with standard English brickwork. At any rate, the quality of the compound brickwork would depend most likely more upon other considerations than on the minute difference in size between the two kinds of bricks. He agreed with Mr. Walton Williams that a levelling-staff divided into separate metres was most inconvenient, and productive of error when read through a level at short distances; but if Mr. Williams would try the levelling-staff mentioned in the Paper, divided throughout into decimetres and centimetres only, omitting metre marks, his difficulty would disappear. Such levelling-staves had long been in common use, and he had used one in Austria for several years. The metric system afforded an ample supply of drawing scales to suit the convenience of the draughtsman and the sizes of his drawing paper; but it was hardly to be expected that conveniently finite metric scales would coincide exactly with the various existing British scales, which had been

adopted on account of their finite relation to the various British measures. If such had happened to be the case, one of the reasons for discarding British measures in favour of metric measures for the sake of facility for international comparison of maps and drawings would not exist. He thought no practical disadvantage would arise, as regarded the convenient size of drawings, if scales of $\frac{1}{50}$ and $\frac{1}{100}$ were used with metric measures instead of scales of $\frac{1}{48}$ and $\frac{1}{96}$ with British measures. It should be remembered that metric scales were not meant to be used to represent feet and inches, and conversely that British scales were not suited to represent metres and their decimal submultiples. As Mr. Thelwall had objected to the waste of figures involved by writing 200 millimetres and 13,000 kilograms, he might economize in them by writing the synonyms 2 decimetres and 13 tonnes. Mr. Airy seemed to have implied that the feet sometimes used in France and Norway were of the same length as the British foot; whereas he understood these feet differed about 1 per cent. and 3 per cent. respectively from the British foot, and if so would be of little value for international purposes. The adoption by Russia of the British foot was an argument, though of limited value, in favour of British measures which had been overlooked in the Paper; but it was probably merely the correction of the length of a foot that had been used in Russia ever since Peter the Great carried home an English carpenters' foot-rule, and imposed it on his subjects as a standard measure. Mr. Hanson had joined Mr. Walton Williams in a defence of the $\frac{3}{16}$-inch to a foot scale; but the advantage claimed for it of suiting the existing divisions on a carpenters' rule would disappear if the carpenters' rule became metric, and the carpenter would then find that the natural scales of $\frac{1}{50}$ and $\frac{1}{100}$ would suit the metric rule quite as well. So far as he was aware, there had never been any question of the metric system affecting the British standard railway gauge, which was practically the same as the standard railway gauges of most countries using the metric system; and he thought Mr. Hanson was hardly justified in assuming that if the metric system were introduced into England, bricks would necessarily be made $\frac{1}{4}$ metre long. He regretted that Mr. Hanson had not stated what the young artisans in France happened to be measuring with a two-foot rule. If, for instance, they were measuring British-made machinery, it might be more convenient to use a two-foot rule for that purpose, on account of the various dimensions of what they were measuring having been constructed to finite British measurements. Many of the incon-

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veniences attributed to the metric system would be found to vanish on investigation. If computers preferred expressing metric measures in vulgar, instead of in decimal, fractions, they were at liberty to do so, nor was there anything to prevent a man speaking of $\frac{1}{4}$ metre instead of 25 centimetres. It had been urged by Mr. Vernon-Harcourt that if metric measures were allowed to be used in Parliament, both witnesses and the legal profession would be much puzzled. He doubted, however, whether the average witness could be as easily puzzled with metric measures after a short experience of them, as he could always be with British measures, while the members of the Parliamentary Bar had certainly sufficient intelligence to enable them to master the metric system in addition to their briefs. He was struck with Mr. Barry's quotation from Lord Melbourne. Lord Melbourne, having attained to great eminence in his own line of life, apparently became disposed to think that changes must necessarily be for the worse. But there were many things, including the methods of measuring used in England, which had not yet been brought to perfection, and it appeared, from the remarks of Mr. Preece and others, there were some eminent members of the Institution of Civil Engineers who thought our time-honoured British measures for engineering purposes might be improved upon with advantage. Almost every large general question resolved itself into a choice between evils, or into a balance of advantages, and the question between British and metric measures was no exception. He contended that, on the whole, the net balance of advantages was so much in favour of the metric system, that all impediments to its use in England should be removed as far as possible; and that it would be to the ultimate interest of English engineers to begin to make use of it for professional purposes. He believed continental experience, as he had pointed out in the Paper, had proved this to be much more easy than many members would have been disposed to think, and the temporary translating of the comparatively few measurements which specially concerned the outside public in the plans of engineering schemes, had not been found so laborious as might have been supposed. In Ireland, land purchased for engineering works had to be computed in Irish land measures, the conversions into which were at least as troublesome as the conversion of hectares into statute acres. Subcontracts for fencing, walling, and even some other kinds of masonry, were in Ireland set in Irish lineal perches, and various local measures had to be used there for purchasing lime, road-

metalling, and some other engineering materials. Any one taking the trouble to investigate the approximate relations existing between metric and British measures, would find rules for approximate and rapid interconversion, which were at least as easily remembered and applied as the many ingenious mnemonics so freely used for abridging British fractional arithmetic and mensuration. Take for instances of the former— Mr. Hamilton-Smythe.

10 lineal metres approximately equal to 11 lineal yards.				
10 square	„	„	„	12 square „
10 cubic	„	„	„	13 cubic „

When once, however, metric measures had supplanted British standard and local measures, all such approximate and other converters would be discarded and give place to more remunerative engineering knowledge.

Sir FREDERICK BRAMWELL, President, said he wished, before the close of the meeting, to ask the indulgence of the members for $0 \cdot 083\dot{3}$, or it might be $0 \cdot 166\dot{6}$ of an hour. What was the object of a system of arithmetic? He supposed that it was to be able to make calculations in the easiest manner, and to arrive at sufficiently accurate results. The question, therefore, was whether the system in use in England, or that in use on the Continent, was the more likely to satisfy these conditions. He felt inclined to say, from many years' consideration and experience, that the English system was the more likely to give this satisfaction. Of course a mere statement of opinion, if unsupported by facts, was of no value, and he therefore desired to give one or two reasons for the faith that was in him. He wished to be allowed to use the decimal system with English weights and measures when he liked, and to use vulgar fractions when he liked. At the present time the metric system was permissive in England, so that any one could use it when he pleased; but he presumed that the object of the Author was to have an Act—a compulsory Act—which should forbid the use of the present English weights and measures. What would be thought by the advocates of the metric system, if those who preferred English weights and measures were to introduce a Bill for the purpose of prohibiting the metric and the decimal method. They would, no doubt, look upon such a measure as being very wrong and improper, and he must be permitted, on the other hand, to regard the introduction of a Bill to compel the use of the metric system as being equally wrong Sir Frederick Bramwell.

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and improper. His hearers must not suppose that the advocates of the metric system were not amenable to the charge of seeking to make the continued use of the existing system a crime. The Bill brought in by Messrs. Ewart, Bazley, Baines, Smith and Graves on the 24th of February, 1868, contained the following penal clauses :—

"10. From and after the expiration of years from the passing of this Act, the Imperial and all local or customary weights and measures shall be abolished, and every person who shall sell by any denomination of weights and measures other than those of the standard metric weights and measures, or such decimal multiples or decimal parts thereof as are authorized by this Act, shall on conviction be liable to a penalty not exceeding the sum of forty shillings for every such sale.

"11. From and after the expiration of years after the passing of this Act, if any person or persons shall print, or if the clerk of any market or other person shall make any return, price list, price current, or any journal or other paper containing price list or price current, in which the denomination of weights and measures quoted or referred to shall denote or imply a greater or less weight or measure than is denoted or implied by the same denomination of the metric weights and measures under and according to the provisions of this Act, such person or persons or clerk of the market shall forfeit and pay any sum not exceeding ten shillings for every copy of every such return, price list, price current, journal, or other paper which he or they shall publish."

There must indeed be an extreme superiority of one system over the other, to justify an enactment that would cause a man to be considered a breaker of the law and liable to penalty simply because he chose to make his calculations by the old method instead of by the new one. All that he asked was, that liberty should be left to people to make their own selection, and he thought if that liberty were continued it would be easy to foretell the result. The permission to use the metric system as a legal measure had existed in England for some years, and in the United States for a still greater number of years, but it had not been adopted; whereupon the advocates of the metric system, not content with leaving it to the selection of the people to use that which was most convenient, wanted to force their particular mode upon them by means of penalties. To come now to a consideration of the relative advantages and disadvantages of the two systems. What were the facts? The Author had spoken of "stones," "drams," "scruples," and so on; but such measures were not used by engineers. He had ridiculed the scale of three-sixteenths of an inch, but, as had already been pointed out, that was

one sixty-fourth of a foot, and he believed that his mind was as capable of grasping the idea of one thing being sixty-four times the size of another as it was of being impressed by the notion that the relative dimensions of two objects were 1 and 100. The Author had brought forward a pair of calculations to illustrate the general superiority of the decimal-metric system above the existing English system; but in one sense, and in one sense only, was this calculation that had been placed before them typical of the metrical and decimal system—in the enlarged copy on the wall the decimal point appeared in the wrong place, as it always did. Some years ago he went into the workshops of the Paris and Lyons railway, where he was shown a drawing of a locomotive, with a variable blast-pipe, and he asked what was the maximum and what the minimum area. One of the engineers took a sheet of foolscap, covered it with figures from top to bottom, and then gave him a dimension rather bigger than that of the cylinder. Sir Frederick Bramwell had a two-foot rule in his pocket, and, finding that the drawing was made on the scale of one-tenth, he applied the English inch tenth, and so got out the area and translated it into French measures, which he did in one-fifth part of the time occupied by the man figuring on the paper. He did not displace the decimal point, because he had not got one. Reverting to the calculations on the wall, he wished to show how utterly misleading they were. The Author had placed before the members two comparative calculations, employed to ascertain the weight in tons and decimals of tons of the water contained in a given sized vessel. In consequence of the bulk of water representing the weight in French measures he was enabled to stop in his calculation on arriving at the cubic contents, and to say, "The whole thing is done; there is the weight of the water; but if you do it in English measurements you will have all these additional figures to use before you can get the weight of the water." Assume for the moment the difference in the length of the two calculations existed, what did it prove as regarded the general question? Nothing whatever. To what did it apply? To fresh water at a particular temperature, and to nothing else. There was no other liquid on the face of the earth, from ether to mercury, for which it would be true. It was not true for salt water, nor would it even do for fresh water at a different temperature. In any other case a multiplier must be used to get the weight, which would make the metric calculation as complex as the Author's English example. But who but one whose mind was warped by the metric system would have thought of turning inches into decimals of feet prior to

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calculation? Would not any one else have worked the sum thus?—

10	6	
6	2	
63	0	
1	9	
64	9	
1	1	
64	9	
5	4	9
70	1	9

The annexed sum showed how any one not saturated with decimals dealing with 10 feet 6 inches by 6 feet 2 inches by 1 foot 1 inch would have treated it. There in twenty-five figures was the answer, as regarded the cubic contents, while the metric system, to reach the same point, had needed thirty-five figures. Mr. Percy Fowler had spoken, to his great astonishment, of the way in which workmen in Spain used the metric system, and made calculations which persons of the same class could not make in England with the ordinary English measures. He had never travelled in Spain, but he had travelled in France, Italy, and Germany, and had made it his business to ascertain what the facts were with regard to the powers of the people to do anything in the way of mental arithmetic, and he said unhesitatingly that in those three countries it was the rarest possible thing to meet a person who could make a mental calculation, not because they were wanting in intelligence or ability, for they were quite equal to the English in those respects, but because they dealt with a system so cumbrous that it absolutely precluded mental calculation. Let any one go to a French railway station, and ask for three tickets from A to B, and it would generally be found that the man (or, as was commonly the case, a woman, with a man to look after her) could not tell the amount without taking a piece of chalk or a pencil and making a calculation. The clerk would have no more idea of what three times the single fare was than a child would have. Compare such a person's power of calculation with that of an English butcher's wife or daughter who was in the habit of dealing with pounds and ounces and pence. Let him test the question nearer home. Could many of those present mentally square 3·25? He believed very few. But there was no difficulty in squaring $3\frac{1}{4} = 10\frac{9}{16}$. $10\frac{9}{16}$ was a sum easily appreciated and easily expressed, while in 10·5625, the decimal equivalent of the vulgar fraction was much more cumbrous, and he ventured to think did not form any impression on the mind, except that it was a little more than one half. Again, which of them could square 4·125? That to the majority would be almost impossible, but with $4\frac{1}{8}$ there was no difficulty. $17\frac{1}{64}$ compared with 17·015625. It appeared to him that a system like the present one, which enabled mental calculations to be made rapidly and accurately, was enough for all practical purposes. It did not lie in the mouth of decimalists to insist upon absolute accuracy, because they were content with approximation, and must of necessity be so

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in many cases. With regard to the statement as to the metre being the ten-millionth part of a quadrant of the meridian, Mr. Hawksley had fully exposed this in his presidential address, to which he would refer the members.[1] The whole thing had been a failure, and Frenchmen themselves did not use the notation, nor did they use the unit of weight. It had been intended, if it were desired to express the thousandth part of a metre, it should be done by writing the word metre, and putting below it a decimal point followed by two 0's and a 1, thus $\overset{\text{Metre}}{0{\cdot}001}$; but what was the fact? A millimetre was expressed by m/m. So with the kilogram. It was intended that should be the unit, and the lesser divisions were to be indicated by a decimal point and the regular number of ciphers, but the fact was the unit was too large, and accordingly the French bought and sold by the half-kilogram, and they called it the ½ kilo, and not 0·500 kilo, or even 500 grams, these modes were too roundabout as compared with "half a kilogram," and humanity would say half a kilogram in spite of penalties. Centimes, again, were often replaced by sous. The "tonne," also, was not a part of the metric system, but was an invention to cure a failure in the system. People did not and would not deal with thousands of figures when they could adopt another mode of expressing the number compendiously by a single figure. As regards the facilities afforded by English weights and measures, he desired to be permitted to refer to the numberless short cuts in mental calculations given by the present system. How much they would have to forego if they were forbidden to say that plate-iron was 5 lbs. to the foot super, and cast-iron 4 inches to the pound, adding $\frac{1}{20}$ to make the necessary correction. Round-iron, by the present system, could have its weight calculated in a moment, squaring the diameter in eighths and dividing by twenty-five, or multiplying by four, gave the weight in lbs. per foot at once; for example, $1\frac{3}{8} = 11$, $11^2 = 121$, $121 \times 4 = 484$ lbs. per foot. Water had been referred to as an instance of the wonderful use of the metric system. He would take a water illustration of a simple calculation by the English system. If engineers wanted to know how much a pump would lift, what did they do? They squared the diameter and multiplied by the stroke of the piston in yards, and at once obtained the amount in lbs., as every yard upon the circular inch was a pound. Taking an 8-inch pump, the square was 64; it was making 10 yards a minute—

[1] Minutes of Proceedings Inst. C.E. vol. xxxiii., p. 342.

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64 gallons a minute—there they had it in a moment. Another instance, 1 inch of rain to the acre was 100 tons, or, to be more accurate, 101 tons. In the United States, where, as here, they had the option to use legally the metric system, they had not used it. Mr. Sellers, one of the best authorities, had said that the thing was not fit to be used. He would refer the members to one who was not a bad engineering authority, Rankine. He would read to them the last verse of Rankine's song in praise of the three-foot rule:—

> "Here's a health to every learned man that goes by common sense;
> And would not plague the workman on any vain pretence;
> But as for those philanthropists who'd send us back to school,
> Oh, bless their eyes, if ever they tries to put down the three-foot rule."

He would also read an extract from a speech of Mr. Beresford Hope on the same subject, made in the debate on Mr. Ewart's Bill:—

"Decimalization is a process of calculation for the benefit of the calculator. Metricalization is not a process, but a system of measures, so called from its unit or base, which happens accidentally to be facilitated by the ease with which its details may be worked out through means of the decimal notation. The metrical system in itself is an abstruse and philosophic one, founded upon the fancy of some French men of science at the time of the Revolution, who adopted as the starting-point of the system the measurement of the earth's circumference, and by way of a unit, measured the 10,000,000th part of a quadrant of a meridian through Paris (about 39$\frac{4}{13}$ inches) which they termed a 'metre.' No doubt those multiples and aliquot parts of the metre which form the French measures of length are adjusted to meet the decimal system, as are also the measures of area, capacity, and weight, which are by a further process built upon the metre. But decimal notation is equally applicable for the man who finds that it helps his calculations whenever he has to work out his sum in our old weights and measures; for decimals are really not a system, but, as I said, a process for easily reaching a certain practical result, like logarithms or algebraical symbols. I grant all the advantages which their friends urge in behalf of decimals for the purpose of calculation; but it requires no Act of Parliament to enable those who appreciate them to make their own calculations by way of decimals. Least of all, is legislation needed for the merchant princes—the men of enormous means and gigantic transactions—whose advocate my hon. friend the Member for Liverpool (Mr. Graves) has made himself. They have but to keep a calculating clerk—an employé whose one duty is to manipulate the decimals—and they have got what they want. The sufferers will be the little people—the small buyers and sellers, the hucksters and the marketers—who will be compelled under the penalties of a compulsory Act of Parliament, to learn and to use a system which is, in its outward type, as non-natural as it is novel. I will, in order to prove my point, take the most familiar instance, and show that although a great deal has been said about the advantages of the French subdivisions, yet, after all, our subdivisions are more natural for the ordinary purposes of life. If a boy has to divide an apple, does he ever think anything

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about the circumference of the earth and its aliquot parts, or about the decimal system and its unrivalled facilities for calculation? No; but he takes his apple, and cuts it into two parts if he wants to halve it, and those halves into quarters if he wants to make four parts of it. In the same way, if a housewife has to cut up the loaf for her family, she divides it into two, into four, into eight, or into sixteen parts, and the sixteen people share their bread naturally. Supposing the loaf to weigh originally a pound, each of these sixteen divisions comes out an ounce. Such is the *rationale* of our system of measuring—the binary system so-called—founded on continual halving, and proved, by the common sense of mankind, before the great era of enlightenment inaugurated in 1789, to be the most convenient and natural one. But I may be told—Halve away, but then express your halvings in decimals. This is very easy for the merchant prince to do when he is totting up his large transactions in 'centals,' or for the Chancellor of the Exchequer when dealing with a nation's finances; but how will it suit the little transactions of daily life? I come back to my loaf. How are ordinary people to represent halves and quarters by decimal points? The symbol of a half is the figure 'five,' with a dot to its left hand; the symbol of half that quantity, that is of a quarter, is the sum twenty-five, also with a dot to its left hand. Arithmeticians understand how this can come about, and the symbols have grown natural in their eyes; but in what—even the most infinitesimal—degree do they tell their own story to the unlearned? What palpable relations towards each other can be disentangled out of these most frequently recurring symbols? What is there in the nature of things to show that the dotted five means a half, and the dotted twenty-five a half of that half, and a quarter of the 'one,' with no dot on either side, which stands for unity? Decimal notation is then, after all, as I have been arguing, a process, and not a system. It is a process good for the schools, and good for the bustling counting-house and the large sum, but the poor man would be completely thrown out if he had to employ—under penal legislation, too—decimal points for the purpose of measuring his little purchases by halves and quarters. With permissive means, such as now exist, the system will come in where it is wanted, and be kept out where it is not wanted; but under a compulsory enactment it will intrude itself everywhere, and show itself in its real colours as nothing less than a public nuisance. But the more we examine the Bill of the hon. Member for Dumfries, the more inapplicable do its provisions seem for the purposes of practical life. I have touched upon the principles of the metric system, let me now call the attention of the House to the language in which (after the French model) it is proposed to clothe that system. The new unit of weight is to be the 'gram' or 'gramme,' which is attained by providing a square vessel, whose capacity is the cube of the hundredth part of a metre ('centimetre,' to wit), and then weighing the amount of water which it will hold at a certain temperature. One-tenth part of this gram is to be a de*ci*gram, and ten times a gram is to be a de*ka*gram, for the reformers decreed that aliquot parts were to be named after the Latin, and multiples after the Greek numerals. How in the name of common sense can we make poor people understand that because there are the letters 'ci' in the one word it means the tenth of a gram, and that because there are the letters 'ka' in the other it means 10 grams, or 100 decigrams? My hon. friends the Member for Dumfries and the Member for Liverpool come to this House representing great commercial transactions; but I stand up for the poor man. Only imagine an honest housewife going into a shop and asking for a decigram of pepper, and a dekagram of tea; imagine, too, the milkmaid selling her fluid by the litre. The Member for Liverpool is a kind-hearted man; is he then prepared, with all the stringent force of a penal statute, to enact that,

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when one of his youthful constituents may desire to effect a commercial transaction in a manufacture for which one portion of that great borough is famous; he should be bound to go to the shop and tender his 'dime' for three decigrams of Everton toffee? Fancy the farmer who has been accustomed ever since he entered on his farm to cultivate the 'ten' or the 'twelve-acre field,' having to consult the steward about liming the seventeen *are* field, or be a criminal and a contemner of the laws of his country. Fancy the bumpkin who was prepared to boast that he was within a decimetre of catching the fox as he crept through a gap about a dekametre from the white gate. If the theorists and the men of wealth—men of brains, it may be, but as certainly men of self-assurance—have worked out this system for themselves, there are poor men, who form the majority of mankind, for whom it will never answer, and there are men of brains at least equal who are decidedly opposed to its adoption. Is it not possible that our present system is not only quite as convenient and useful as the metric system, but a little more philosophical also? Why should a standard founded on the quadrant of the earth's circumference passing through the meridian of Paris be a better one than ours? No doubt it looks very solemn, from the grand nomenclature with which it is propped, but all those odd names for the French weights and measures were adopted at the first heat of the great Revolution, when the pedantic aping after ancient Greek and Latin terms led to their being applied to everything novel and French—from the scanty proportions of a lady's dress to the most intricate principles of jurisprudence and moral philosophy. Moreover, they have taken root in nations whose vernacular languages are themselves derived from the old classical tongues. May it not, I repeat, be just possible that our unit is as good as that of the French, even upon the most abstract grounds?"[1]

Mr. Beresford Hope, having spoken in that commonsense way, had quoted a letter from Sir John Herschel, which was very well worth reading, but he would not detain the members with it. He would only refer to one other matter, and that was the coinage. It had been said, you may decimalize the pound without difficulty. This was one part of the case which had not been considered. Once let the pound be decimalized, and there would be an end of the guinea. He did not know whether there were any physicians or barristers present, but if there were he would remind them that by the new system they would lose 0·047619 of their incomes—in other words $\frac{1}{21}$. When the pound was decimalized no one would be prepared to pay the next division, which would be $\frac{1}{10}$ instead of $\frac{1}{20}$. In conclusion, he would tell them of a ready way which he always used for mental calculation when turning millimetres into inches. Mr. Rapier had said, multiply by 4, but this needed a correction, which was, deduct $\frac{1}{64}$ of the product; this would give an answer as near the truth as the 3 .. $3\frac{3}{8}$ commonly taken; for example, 16 millimetres $\times\ 4 = 64 - \frac{1}{64} = 63 = 6\cdot 3$ inches.

[1] Hansard's Parliamentary Debates, vol. cxcii., May 13th, 1868.

Correspondence.

Mr. A. Barclay remarked that there was a convenient mode of graduating and figuring a rule which was applicable to any arbitrary unit and subdivision. In the ordinary fitters' and joiners' English two-foot rule, folded in the middle on a compass-joint, the inches, figured on each face from left to right, 1 to 24, were usually divided into $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{16}$. If any work had to be centered, the unit end of the rule was made to correspond with one limit, and the reading was taken at the other limit (say $21\frac{3}{4}\frac{1}{16}$ inches bare); it was then necessary, mentally, to halve this quantity, represented by two numerals, two fractions, and the difference to the nearest division; and having by this process obtained the new half quantity ($10\,\frac{7}{8}\,\frac{1}{32}$ inches scant, which had also two numerals, two fractions, and a difference), to note the corresponding reading on the rule, and against it make a trial centre mark, which was very likely to require adjustment. Next the accuracy of its position must be checked by an equal half measurement to the other limit. The rule which he preferred had the usual divisions and figures, and also on one face next the outer edge were two scales of half-inches figured 1 to 24 from the joint to each end, the half-inches having the same number of sub-divisions as the scale of inches. With this rule, having ascertained the cross measure (say, as before, $21\,\frac{3}{4}\,\frac{1}{16}$ inches bare), and found the corresponding figures and divisions on the two half-inch scales, they would, when laid on the work, exactly coincide with the two opposite limits, and the centre would be marked off with confidence at the joint zero. It was only necessary to remember the first measurement as a comparative length, calculation was unnecessary, and halving a measurement by this method of substituting the appropriate scales was accomplished with accuracy and dispatch. The Japanese artizans, now at work at the Exhibition at South Kensington, used a bamboo rule of native make, like a drawing-scale, the unit being the English foot divided into 10, 100, and $\frac{100}{2}$. Mr. Barclay.

Mr. H. Bauerman, as the result of long experience in the use of various metrological systems in different countries, was unable to agree with the Author's conclusions as to the desirability of internationalizing the metrical system to the exclusion of all others. He thought that the weights and measures used at any particular time by any people fairly corresponded to their local and temporary necessities, and as new necessities arose, they would be met by the adoption of new, or by the modification of old, units. Take, for instance, the progress in the use of the ton as a business unit. For Mr. Bauerman.

Mr. Bauerman. many centuries commercial requirements were satisfied by the hundredweight or quintal, and indeed the latter, until lately, if not now, did survive in the Newfoundland and Labrador cod fisheries. Increase in the scale of operations, however, led to the adoption of the twenty-fold larger unit, first in England, and at longer intervals in foreign countries. Strangely enough in Germany, where the cwt.-unit lingered longest, the ton had been supplemented by a ten-fold larger unit, the wagon, corresponding to the contents of a ten-ton railway-wagon, which was now commonly used in the coal and iron districts of the Rhineland. These were examples of change of use due to commercial necessities, and which had been effected without inconvenience; but it would be very different to attempt to impose an entirely new metrological system upon a people without regard to local usages. Those who advocated the universality of the metric system seemed to consider arithmetical convenience as synonymous with convenience of every kind, which was not necessarily true. For instance, when a large number of similar articles had to be divided into small packages, there was a distinct saving of packing materials by making them up in twelves rather than in tens. Here the convenience of the packer was in sharp contrast to that of the computer, so that while the latter might prefer to consider twelve as 1·2 decade, the former would regard ten as five-sixths of a dozen, and it would only depend upon the relative strength of the two parties which view should prevail, if one were to be used to the exclusion of the other. The Author's arithmetical illustration did not appear to have much bearing upon the question, for although he had used a large number of figures to arrive at an incorrect result in determining the contents of the English tank, as contrasted with a smaller number required for the determination of the equivalent metrical volume, the former was due to the use of incorrect factors and an inappropriate arithmetical method, which again was conditioned by the assumption that civilized arithmetic must necessarily be decimal. In other words, he preferred multiplying by 0·167, which was inexact, to dividing by 6, which was right. The Author's suggestion that English engineers would be precluded from using foreign technical literature, because in the latter, dimensions were, as a rule, expressed in millimetres, did not seem to accord with the experience of the Institution, which for some years past had supplied abstracts of the more important Papers in foreign journals, in English, but in many cases with the original dimensions. These had been so far appreciated as to be largely reproduced in English and American journals when of special interest,

which would scarcely have been done had the editors considered them as a matter unintelligible to their subscribers; and in the case of one contributor at any rate, such abstracts had led to correspondence sometimes of an enquiring and sometimes of a mildly controversial character, but in neither case had there been any misapprehension as to dimensions. The Author's views as to decimalizing English money were also contrary to experience. The physical decimalization of the sovereign had been attempted in England by the issue of double shillings, which were intended to supersede half-crowns, and the coinage of the latter was discontinued for many years; but when they became scarce the public asked for a further supply, and got them, whereby the decimal system pure and simple was tacitly abandoned, but at the same time public convenience was enhanced by having the two kinds of coin instead of only one kind. The Latin Monetary Convention in its present form was rather intended to reduce the circulation of a token coin, the franc of $\frac{835}{1,000}$ fine, than to facilitate its international currency. Mr. Bauerman.

Mr. F. BRIFFAULT pointed out two instances that had come under his notice in connection with two foreign waterworks where the decimal and metric systems alone were used. The Brazilian Government had been supplied with 95,000 tons of pipes and connections from this country for the waterworks of Rio de Janeiro, this quantity being divided between four manufactories. The castings were all weighed in kilograms, the weighing-machines having been made expressly for the purpose. At first the men did not take kindly to the innovation; but at the end of a fortnight, after finding out the great saving of trouble thereby effected, they much preferred this system to the British. Having only to deal with one unit of weight, the kilogram, the numbers were at once read off the weighing-machine; and at the conclusion of the day's work the columns were added up, and three figures pointed off to the left gave of course the total in metric tons. Only simple addition being necessary, the class of men entrusted with these operations could do their work without error, whereas had the weight been of several denominations, a hopeless muddle would have arisen. At the termination of the contract, there was only a discrepancy in weight between the Government authorities and the contractors of under 3 tons. Considering the magnitude of the undertaking, such a result would scarcely have been attained had British measures been used. There had also been a great saving of time and money in clerks' salaries by the adoption of this system, in the two and a half years occupied on the work. In the Mr. Briffault.

Mr. Briffault. case of the Constantinople waterworks, similar satisfactory results had been obtained by the use of the decimal system; but in Turkey the advantage of it over the British system was even more marked. The number of pipes arriving damaged and cracked in transport up country was very great; they had consequently to be cut on the spot in order to be utilized; and there was thus a great variety of lengths to deal with. To weigh the pipes after cutting was impossible for many reasons; so the reduced lengths were measured in metres and centimetres, and the maximum weight allowed per lineal metre being fixed, the two had but to be multiplied together, and the result was metric tons and decimal parts of the same. With feet, and inches, and tons, cwts., qrs., and lbs., a vast amount of tedious work would have been necessary, and with a doubtful result as to its correctness.

Mr. Chapman. Mr. W. D. CHAPMAN remarked that in the "Standard" of the 16th of December, 1884, there appeared a leading article to the effect that a Dutch company could sell Dutch milk in London "at the price of $2\frac{3}{4}d.$ per litre—or, in other words, at a little over $2d.$ per quart." On proceeding to check this calculation, he found that $2\frac{3}{4}d.$ per litre was $3\frac{1}{8}d.$ per quart—a difference which completely disposed of the arguments in the "Standard." He thought that many practical English farmers, interested, as he was, in English dairy-farming, had been misled by having to assume the accuracy of the erroneous conversion of measures, and had needlessly admitted the hopelessness of competing with the Dutch company, simply because the want of an international language of measurement deceived them as to the facts of an enterprise affecting their business. This was merely one recent example of many cases where English business had been fettered, and English business men deceived, in questions of international competition where measures were concerned.

Mr. J. Craig. Mr. JOHN CRAIG observed that most of the advantages and disadvantages of substituting the metric system of weights and measures for the British system had, no doubt, been fully entered upon and discussed. He wished only briefly to add his experience of the working of both the above systems, and also of other systems in various countries. Great weight must be attached to the remark in the Paper as to the position held by England and the United States of America in the manufacture of engineering machinery. It was generally admitted by engineers that any violent change of the measures now in use would be practically impossible, as far as this branch of mechanical engineering was concerned; besides, a strong feeling existed amongst many mechanical engineers against any change; they even asserted that British measures

were, for their purposes, better than any others in use. No such feeling existed amongst civil engineers; nor would interests be affected in anything like the same degree if the metric system were at once generally adopted in connection with all field- and office-work undertaken by them, for which the consent of Parliament had to be obtained. He had never met a civil engineer who had used the metric system in field and office, on railway or other public work, who did not admit its great superiority to the British. If his experience agreed with that of the majority of the civil branch of the profession, he submitted that steps should be taken to have the metric system allowed, or enforced, on all public works; its use would thus become known, and gradually extend, and the way prepared for the time when the metric system, or other system based on somewhat similar principles, should be adopted by all English-speaking peoples. Literature, in connection with all branches of the profession, would soon adapt itself to a new order of things. It had been said, "To acquire a new language is to enter upon a new world." The advantages a British engineer would gain by a literature written in terms of an almost universal measure with which he was familiar, would be great indeed. The advantages derived from the nomenclature of the metric system, although great, were, he thought, of secondary importance; that was, if the nomenclature should in any way prove a bar to the system coming into general use. He would prove a benefactor to his country who would suggest some good plan whereby he could retain many familiar names for certain of the metric dimensions. The adoption of the metric system in India, on the Government and public works, so far as might be required for engineering purposes, would not cause much inconvenience, especially if time were given. In most, if not in all the Colonies, the change would be hailed with joy, and would form a not unimportant link in the chain which was gradually being forged, to bind them in one mighty federation with the mother-country. In some of the colonies its adoption would do away with the difficulty of introducing British measures amongst peoples under our rule, whose system of weights and measures might be as good as ours, and whose likes and dislikes were quite as strong. At the Cape, for example, all railways and public works were carried out by the use of British measures. Land was, however, surveyed, bought, and sold by Dutch measurement. The colonial ton, of 2,000 lbs., and cwt. 100 lbs., could not, he thought, with advantage be replaced by the British ton and cwt. In the markets of the country the measures were most confusing, and there was certainly great

Mr. J. Craig.

Mr. J. Craig. need for reform. To have a decimal system of coinage would no doubt facilitate the use and introduction generally of the metric system. The great convenience of a decimal system of coinage could only fully be realized by those who had resided for a time in a country where such a system was in use. He feared, however, the opposition to change would be very great. Time could not be given for it to come gradually into use, and a change when made must be compulsory on all. He did not think accounts would ever be kept in pounds sterling and mils. The pound sterling must always remain, but florins and cents could easily be substituted for shillings and pence, and the British penny might still remain a force in the land, in name and appearance. Accounts kept in the above way would effect a saving of 20 per cent. in the number of figures required on a page of a written-up ledger, to say nothing of the advantages in other ways.

Professor J. D. Everett. Professor J. D. EVERETT agreed with the Author in thinking that the adoption of the metric system of measures and weights would be a great benefit, by effecting a saving of a vast amount of useless labour. The case had, he thought, been fairly and clearly stated in the Paper. He was glad to find one point insisted on which had often been overlooked, namely, the facility which a decimal system afforded for logarithmic calculation. The remark must be extended not only to the use of tables of logarithms, but to the use of logarithmic scales, such as the slide-rule in its ordinary form, or in the circular form, or in the parallel-column form employed in his "Proportion Table," or in the helical form which, in Professor Fuller's "Spiral Slide Rule," admitted of working to five places of figures. He concurred in the importance of speedily decimalizing the British money reckoning and coinage. Any partial decimalization of the coinage, not carried far enough to admit of keeping accounts decimally, was of no advantage. In his opinion the arrangement that would least disturb existing prices would be to decimalize upwards from the farthing, because every sum of money, according to present reckoning, would have an exact equivalent in the new reckoning, whereas the present penny and halfpenny would have no exact equivalents in a system decimalized downwards from the pound sterling. But a minimum of disturbance was not the only consideration. He was in favour of neither of the systems above compared, but had for many years held the opinion that the best system to adopt would be the American system of dollars and cents. When travelling in America many years ago, he was greatly struck, not only with the facility afforded for calculation, but with the extreme convenience of the coinage. An abundance of change for all sorts of purchases

could be carried without burdening the pocket, and though a stranger, he could count his change with as much ease as in his own country, and with much more ease than in France, notwithstanding that the coinage there was likewise decimal. He claimed that the American system was more economical of space in account books than either the French system or a decimalized system founded on the pound sterling. It started from the cent (about a halfpenny) as the unit in the right-hand column. A decimalized system, founded on the pound, must start from the mil as the unit in the right-hand column; for the hundredth of a pound (2½*d.*, nearly) was too large for less sums to be ignored. The pound would therefore be the unit in the fourth column from the right hand, and space must be left for three columns to the right of it. In the American system only two columns were wanted to the right hand of the dollar column, so that the unit in the fourth column from the right hand was ten dollars. This was rather more than two pounds sterling, and thus with a given number of columns twice as large a sum could be expressed in the American system as in the pound and mil system. The disturbance of prices would be much less than in the pound and mil system, for 100 cents were 4*s.* 1½*d.*, and 100 halfpence were 4*s.* 2*d.* The difference between a cent and a halfpenny was therefore 1 part in 100, whereas the difference between a mil and a farthing was 4 parts in 100. He thought the importance of adhering to the pound sterling in its exactitude had been greatly exaggerated, and he believed that no confusion would be introduced in foreign relations by making payments in five-dollar gold pieces, each worth £1 0*s.* 7½*d.*, instead of in sovereigns as hitherto. Professor J. D. Everett.

Professor H. HENNESSY observed that the utility of a complete international system of weights and measures, based on the existing international system of counting and calculation, seemed to be clearly established, and the Author of the Paper had shown that no profession would profit more by such a system than the profession of civil engineering. If the whole question were open to revision, probably a decimal metric system, founded upon a standard of length common to all nations, such as a fraction of the earth's polar axis, would be most acceptable. This had been proposed by Professor Hennessy long since, and a complete series of measures and weights derived from it had been exhibited at South Kensington in 1876. It fulfilled all requirements of a complete system, and on account of the close approach of one of its fractions to the existing British inch,[1] it was strongly supported by some eminent Professor Hennessy.

[1] The polar inch differed from the British inch by the thousandth part or less.—H. H.

Professor Hennessy. persons including the late Sir John Herschel. But when he reflected on the fact that the majority of the civilized part of mankind had already adopted the French metrical system, and that every day this system was becoming more familiar to British students of engineering through their observation of foreign works, or perusal of foreign scientific and technical publications, he could not hesitate to express his concurrence in the views of those who advocated its adoption for all nations. Some inconveniences would have to be endured for a short time before workmen and calculators were familiar with the new system, but these inconveniences had been cheerfully encountered by great nations already, and their experience might be fairly appealed to in answer to this difficulty. Men of science and engineers, whose minds were accustomed to accurate estimates of number and magnitude, would in general have no difficulty in employing more than one system. Thus, while he had found it advantageous to use the decimal metrical system in applied mechanics, thermo-dynamics, and mathematical physics, he had been often obliged also to employ the British system, on account of its use in ordinary applications. But this very circumstance had only made the superiority of the metrical system more distinctly felt, and made him more than ever desire that it alone should be employed throughout the world.

Mr. Hett. Mr. C. L. Hett remarked that in 1870 the Butterley Company obtained the contract for the Dordrecht Railway Bridge, and he had prepared the drawings for the steam cranes, scaffolding, &c., required in its erection. As the piling and superstructure of the staging had to be erected by a Continental contractor, the drawings were made to metric measures. Drawing-scales were ordered having the most generally used English graduations on one edge, and corresponding metric divisions on the other. By the use of these scales all difficulty was overcome, and rapid progress made. The drawings of the bridge itself were prepared in Holland, under the supervision of the Dutch Government engineers, and were dimensioned in metric figures throughout. But in the works there was an outcry. The men at first said they could not, and would not work to such outlandish dimensions. The purchase of a few metric rules, however, settled the difficulty; and after a fortnight's practice, one of the old hands who had been most opposed to them, admitted that the metric measures were much the easiest to use; especially where an even pitch could not be employed, but a given number of equidistant rivets had to occupy a certain space, the pitch being an odd dimension. It should be mentioned that no member of the Butterley staff nor any of the workmen had had any previous ex-

perience of metric measures. The absurdity of the present system of measurement was well exemplified in the case of railway-bridges and of drainage pumping-works. In each case a plan of the site was supplied drawn to a scale of chains and links, the heights being given in feet and decimals of a foot, while the drawings for the ironwork were made in feet and inches. The standing arguments used against the metric measures were the Whitworth screw-threads, the 1-inch and 6-inch ordnance maps, and the loss that would accrue from the depreciation of patterns and templates. The former difficulty was not felt abroad when the metric system was established, any more than inconvenience was experienced at home from the odd diameters of the standard gas-threads. The second objection could be removed by engraving metric scales on the plates from which the maps were printed. At present, owing to the variable contraction of the paper, accurate measurements could only be taken with the scale printed on the maps. Even now the ordnance maps on the larger scales were made without regard to the time-honoured yard and inch, being plotted to scales of $\frac{1}{2,500}$, $\frac{1}{500}$, &c., of the actual size. On such maps, metrical scales could be used with great convenience, but a rule divided into inches was valueless. The last objection appeared at first to be a very important one, yet it was more so in appearance than in reality. A thoroughly good set of patterns or templates would retain their value, while obsolete ones would probably be destroyed rather sooner than if there had been no change in the measures. Mr. Hett.

With regard to the British system, or rather want of system, of weights, little need be said. In trying to improve them, matters had only been made worse. The cental of 100 lbs. originated with the Liverpool corn-merchants, who, after using it illegally for years, obtained Government sanction for its adoption in 1879. It was expected to effect a reform in the sale of corn; but nothing of the kind had occurred. A Bill had been laid before the House of Commons to render the use of the cental compulsory in the corn-trade of England. The scheme of decimalization of the coinage mentioned by the Author, and which had been so frequently advocated, might be easily introduced. The poor would approve of it, as they would get 12½*d.* for 1*s.*; but the difficulty would be in the temporary loss to the revenue of 4 per cent. in postage and receipt stamps. Although this subject had been thoroughly discussed years ago, it was under very different conditions to those which now prevailed. At that time there was hardly a competitor with England in the foreign trade. The British were virtually in a position to dictate to countries employing the metric system, and

Mr. Hett. to say, "There is our machinery made to our measurements, and without the slightest consideration of your convenience." But now it was different; there were makers from countries employing the metric system ready to supply any order for machinery, and year by year the excellence of their goods would be improved until their workmanship was equal to our own, and our last advantage over them would be gone. It was sometimes urged that if the United States did not adopt the metric system, why should England? The Americans were agitating for its adoption; and the first country to change would have a great advantage in trading with those other nations who had already adopted it. At the same time America did not purchase machinery from the British, and therefore their case need not be considered. Now that education was compulsory, the extra work involved on the rising generation and their instructors by the clumsy system of English weights and measures should be carefully considered. As so much was being spent in education, and cases of "over-pressure" were so frequently reported, should not an effort be made to abolish a system which was admitted on all hands to involve an enormous amount of unnecessary labour? The feeling that the metric system must sooner or later be adopted was not confined to engineers and scientific men; it was shown by the action of the Leicestershire Chamber of Agriculture in 1878, which opposed the legalization of the cental on the ground that it might impede the adoption of metric weights and measures. Few persons attempted to defend the present system, yet there was a general hopelessness of any change. Improvement had been advocated; but any alteration would involve greater confusion than a total change, while the international character of the metric system would not be attained. The importance of the subject was so great that Government might be asked to aid the change by adopting the metric system throughout their departments. If adopted exclusively in the customs, metric weights would immediately be made the basis of railway charges, much to the relief of goods' clerks and accountants. Wholesale houses would follow, and gradually the system would be accepted by the small retailers.

Mr. Hurter. Mr. Ferdinand Hurter, Ph.D., held that the only important reason for a change from the English to the metric system was that many nations had adopted the latter. Perfect internationality was, however, impossible, since Germany had not adopted the coinage of other continental countries. The metric system did not save so much time as was usually claimed for it. Where a decimal system was obligatory, the English people used it. True, it required

more time to attain a knowledge of the English system and its special arithmetic at school; but that time was not lost, and the pupil who mastered the greater difficulties became the better man in the end. The examples of saving of time which the Author had given were not very well chosen. If the French carpenter had a folding metre-rule, he would not measure more quickly than the English carpenter; if the rule were not jointed, give the carpenter a five-foot staff or a measuring tape. The multiplication, which the Author supposed the carpenter to make, was never made to his knowledge. The carpenter said 2, 4, 6, &c., as he turned the rule over. He was certain that a man well acquainted with his business could accomplish as much work, on an average, by the English system as he would by the metric system, and in considering so important a question as a change from one system to another, the difficulties which the system presented to the uninitiated must not be left out of sight. The calculation of the weight of water in a tank could have been much shortened by abandoning the decimals of feet, and by remembering that 1 ton of water was 36 cubic feet (error 0·2 per cent., or 5 lbs. to the ton). One point had been overlooked by the Author, namely, that the one-foot rule was as often used as an instrument for subdividing as it was to obtain data for a calculation. In this respect the one-foot rule, with its binary and ternary subdivisions, was as much superior to the metric rule as a circle divided into 360° was superior to one divided into 100°. Suppose it was required to subdivide 1 metre, this could be done by means of one thousand divisions in fifteen different ways. Take the same length, 39$\frac{3}{8}$ inches, and use an English two-foot rule, divided into sixteenths of an inch, and there were twenty-three ways of subdividing it into equal parts, though the eye had only six hundred and thirty divisions to examine, instead of one thousand. But compare the yard in this way; it could be subdivided by means of an English rule, obtainable for 3s., in forty-two different ways. It was in the workshop that the English system was superior to the French; and the English inch was the standard for screw-cutting, not only in England, but throughout the world. It must not be forgotten that the British public was not prepared, nor preparing for such a change. Decimal calculation was unknown to the mass of the people. Boys were allowed to leave school, having passed the fifth standard, void of all knowledge of decimal arithmetic. Surely it would be unfair to take the masses by surprise! But if the metric system must be, let it be the metric system pure, the metric system compulsory; not a metric system at the option of any engineer. Let

Mr. Hurter.

Mr. Hurter. there be no mixture, particularly in plans to be submitted to, and discussed by, parliamentary committees.

Mr. Jackson. Mr. L. D'A. JACKSON observed, with regard to the choice between British and French metric measures, that British engineers dealt more with persons of their own nation, with colonial English, with citizens of the United States of America, and with semi-civilized and barbarous nations, than they did with nations that had adopted the French metric measures. Hence British measures were preferable for the English engineer. It was also important to notice that Russia used British measures in part. This first guide to choice should certainly settle the matter. Next, the British measures were good, useful, suitable, and convenient measures, while the French metric measures were mostly mere nominal units, among which there were only three or four useful measures. Lastly, there was no excuse for adopting the bad measures of the French in England, where a single, though incongruous, system already existed. When the French, the Italians, and the Germans adopted them, they had booksful of various measures of their own, and their internal jealousies prevented them from selecting among the best of those well known to themselves. Moreover, the installation of the metre was effected by fine and by imprisonment, the leading men having been previously won over by flattery. Engineers found that the British measures were inconvenient for purposes of calculation. If, then, they wished to decimalize, let them decimalize on their own existing units, thus keeping themselves in accord generally with the measures of their own nation. The selection of British units for decimalization should be left to committees of experts. In the interim engineers should be allowed, by Act of Parliament, or by Order in Council, to decimalize without restraint on any or all of the existing British measures, with the sole restriction of adherence to some one unit and its decimal multiples, and sub-multiples, in each class of measure. The difficulties would be few, as any one complete decimal system was easily comparable with any other complete decimal system within the separate classes of length, surface, cubic and weight units.

Professor Jenkin. Professor FLEEMING JENKIN said he should like to record his opinion that if any change were made by engineers in their standards of measurement, they should adapt the C. G. S. system, as it was called, with absolute derived units for force, &c. This change must, in his opinion, be made sooner or later, whether engineers liked it or not; and any half measure, such as taking a kilogram as a unit of force, or a kilogrammetre as a unit of work,

would only entail additional inconvenience; but dynes and ergs had a clear practical advantage to recommend them. The C. G. S. system (centimetre, gram, second) had been already sanctioned as regarded electrical measurements by the International Conference of 1883 and 1884, held in Paris under the presidency of Mr. Cochery. This was the thin edge of the wedge, and since the wedge was a good strong one, and the motive for driving it home was of overwhelming importance to physicists, driven home it would be. Those who wished to know what the C. G. S. system was might consult Everett on "Units and Physical Constants." If this system had been in practical use, Professor Jenkin would have been saved one-half the labour in preparing his lecture on Gas Engines, which he had delivered before the members of the Institution. Professor Jenkin.

Mr. S. W. Johnson remarked that for the last twelve years the decimal system of measurement on the Midland Railway, referred to by Mr. Fernie in 1863,[1] had been employed only for the tire-boring, for contraction, and for the purpose of measuring test-bars, while Whitworth's templates and gauges were in use for all other workshop details. Mr. Johnson.

Mr. T. J. Nicolls observed that the incongruities and anomalies which were of daily experience under the accepted methods of weighing, measuring, and valuing, might be illustrated by reference to "Portland cement." The evil was first apparent in the specification, drawn more or less in the following general terms: "The cement shall . . . and weigh . . . pounds per bushel (striked); . . . per cent. must be retained on a sieve of . . . meshes per square inch; and bricks of the neat cement must be equal to a strain of . . . pounds per square inch. The tests will be applied to . . . bricks in each lot of . . . tons, &c." But this did not exhaust the weights and measures connected with cement. It was sold "by" the ton (never by the bushel), and "in" either bags or casks of indefinite, varying, bulk and weight. It was commonly used by the cubic yard (concrete), or square yard (plastering, flooring, &c.). The annexed table presented a transaction in Portland cement, in terms which were hardly credible as being those of actual experience; cement was Mr. Nicolls.

Specified for density	per bushel.
The full of the bushel to weigh so many . . .	pounds.
Bought "by" the	ton.
Delivered "in"	bags or casks.
Tested for fineness	per cent.
,, over so many meshes per inch depending on.	S. W. G.
,, for strength in lbs. per	square inch.
And used by the	cub. yd. or sq. yard.

[1] Minutes of Proceedings Inst. C.E. Vol. xxii. p. 606.

Mr. Nicolls. Surely the fittest parallel to such application of figures as Portland cement evidently required, was to be found in the old farmer's clock which, to those who knew its ways, told half-past four in the day by striking twelve and pointing to five minutes to nine. A similar juggling had to be performed in dealing with iron. It was generally held to

Weigh . . . . a decimal of a pound per cubic inch	or pounds per square foot 1 inch thick.
Was measured in	feet and inches.
Priced and bought per	ton.
Tested for tensile strength in pounds per . . .	square inch.
„ for elongation decimally.	per cent.
„ for deflection by a binary subdivision of the	lineal inch, or by per cent. of span.

To give an additional example: take the apparently simple case of estimating the weight of rails per mile of railway—

Rails, say	80 pounds per yard.
The multiplier for pounds per mile was . .	1,760 !
And the divisor for tons per mile was . .	2,240 !

Compare the arithmetical process involved by these figures with the methods of arriving at the number of units of gross weight under the decimal (metric) system, which was, so to speak, automatic.

Rails, say	40 kilograms per metre.
Both { multiplier for weight (kilog.) per mile (kilometre) and divisor for tons (milliers), though little used }	= 1,000.

Thus the arithmetical process was effected immediately, and the required result obtained by simply changing the names of the multiplicand from kilograms to milliers.

To revert to the units in the case of Portland cement. It would be observed that only "pounds" and "tons," and "square inch" and "square" or "cubic yard" had any fixed relationship, according to any tables in existence; and for purposes of calculation, these relationships were represented by the numerical expressions $\frac{1}{2{,}240}$, and $\frac{1}{36 \times 36} = \frac{1}{1{,}296}$, and $\frac{1}{36 \times 36 \times 36} = \frac{1}{46{,}656}$; while under a decimal (such as the metric) system, the representative fraction would be $\frac{1}{1{,}000}$ or $0 \cdot 000$, and sub-multiples or multiples of it. The bushel was said to be of a capacity which, stated in terms of

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British units, simply could not be measured. On the authority of "Molesworth" it might be taken as equal to 2,218$\frac{16}{100}$ cubic inches = 1$\frac{28}{100}$ cubic foot. The inch and the foot (which were much too small and too large as units of minimum dimension), were defined, or at least, their sizes were accepted, conventionally. Not so the pound weight. The British "system" boasted two distinct pound weights; and while those who knew what was meant, professed to find things easy, it could not be quite so clear to foreigners who might wish or require to refer to English calculations.

A popular magazine had lately informed its readers that a "grain" of gold might be beaten out to cover 56 square inches with leaves only $\frac{1}{22,800}$ of an inch in thickness. What did the statement convey to the general reader as to the relationship of the "grain" to the "inch" square or lineal? None; there was no such relationship. Casual readers might forget that there was any use for the word "grain" so applied, other than as a rough indication of minute bulk; but ancient history traced connection between it and the grain of wheat as a measure of weight; yet it might be that the "grain" of gold referred to would but ill compare with the grain of wheat either as to size or weight. Hence the particulars in the statement, though not detracting from the wonderful ductility of gold, were wholly worthless as a comparison of actual facts. Any one having more or less intimate knowledge of workshop practice, or intercourse with the foremen of departments, would realize the contortions of memory, and the evolutionary processes necessary to enable the mind to comprehend the rough cube of a piece of stick which was announced to be 2 feet 1$\frac{3}{4}$ inch long, 4$\frac{5}{8}$ inches broad, and $\frac{7}{8}$ and $\frac{1}{16}$ inch thick. Such an experience might be compared with the equally systematic measurement of a timber log by a farm hand: "Five times the length of my stick, twice the length of my foot, then this straw, then half a brick, and a bit over." He had heard a University Professor and a Fellow of his College boast to his pupils, that he had never mastered and did not "know" the English tables of weights and measures. The professor always had his sympathy.

It was to be hoped that the Paper would lead to useful results. The advantages of the alteration it advocated were far from being overrated; they were such as seemed to afford an occasion for the origination of a movement having in view the final substitution of a simple and attractive system of numbers, already well tested, for the present anomalies, and the illogical jumble of terms and quantities. It would not be enough to decimalize the British tables of weights and measures; that was

Mr. Nicolls. impossible, however practicable to deal in that manner with the coinage. Sooner or later there must be a complete decimal system for all purposes of calculation and measurement. It was to be hoped that it might not remain to be secured for the English, as it had been for the French, among the results of a sanguinary revolution.

Mr. Parker-Rhodes. Mr. C. E. PARKER-RHODES, late of H.M. Consular Service, was in favour of the metric-decimal system in substitution for the present British weights, measures, and coinage. In the adoption thereof for all purposes no difficulty would arise, even in ordinary commercial and trade transactions, particularly in the measurement of land. As to advantages, he need only state that a case of survey had recently been submitted to arbitration at the Surveyors' Institution, in which an error of 1 acre in excess existed where the correct quantity was a little over 2 acres. Saving of time in calculation was likewise in favour of the system now acknowledged by numerous states; and by the diminution of operations and figures the memory was less taxed. The liability to error was also reduced to a minimum. The conversion of British weights, measures, and currency in foreign countries would always be to the disadvantage of British interests, at the same time resulting in considerable fluctuations. International uniformity was greatly needed, as might be proved by the importations of all commodities under the British flag in foreign countries.

Professor R. H. Smith. Professor R. H. SMITH thought experience proved that there was no great difficulty in introducing new measures into the practical life of a nation; certainly not as regarded engineering practice. Putting the case of France aside, Germany, Russia, Italy, and Austria, had adopted the French metric system throughout practically the whole of their engineering work, and had become familiar with it within a comparatively short period. Again Sir Joseph Whitworth's workmen used a system different from any other, namely $\frac{1}{10}$ inch, and this without difficulty or liability to error. In the workshop, liability to error was, under existing circumstances, more often due to the workmen having a variety of conflicting scales marked on their rules than to any other cause. The theoretic objection most commonly made to the metric system was that the duodecimal division was more advantageous than the decimal. As a matter of theory he thought this argument mistaken. There was a real necessity for representing the fraction $\frac{1}{2}$ in the simplest possible fashion, whatever system might be adopted, because of the great physical importance of binary symmetry for the sake of balancing weights, &c. The great majority of dimensions was for such reasons marked off in halves,

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but beyond the fraction ½ he thought no fraction had any more importance than another. Physically the dimension of 0·88 inch would suit every purpose just as well as ⅞ inch. Physically it was just as convenient to buy in 0·765 ton of iron as 15 cwt. If the 0·75 was preferred, it was only because the notation made 0·75 a little more easy to calculate than 0·765. If the notation adopted made it easier to reckon 0·765 than 0·75, then the commonly used fraction would be 0·765 and not 0·75. Therefore so long as the system of notation represented ½ simply, *i.e.*, so long as its base was an even number, he thought it of little theoretical importance what base was taken. Obviously 2 or 4 was clumsily small because with these, large numbers would be represented by great arrays of figures. Practically it was of the utmost importance to adhere to 10, because, although he believed it would be easy to introduce new physical quantitative units, he knew from repeated attempts that it was extremely difficult to change the fundamental idea of numerical notation; and also because the decimal system was not only deeply ingrained in our minds, but was wide-spread over the world, there being no nations having any notation at all, who did not count by it. No one who had lived and worked on the Continent, and who recollected at the same time what was the usage of scientific men all over the world, could for a moment contemplate the possibility of converting the continental peoples to the use of British measures. It followed that if an international system of measurement was to be attained, it could only be accomplished by the approximation of British to the best metric system that would be generally acceptable. Men devoted to pure science used now almost exclusively the centimetre and its derivatives. He believed the centimetre was commonly used in France by engineers also. In Germany, however, the millimetre was almost universally employed by engineers as the unit of length. The reason evidently was that the centimetre was too long to make it possible even commonly to avoid fractions in dimensioning drawings, &c. In calculating the diameter of a shaft, for instance, it would be most improper to round off the result to a whole number of centimetres, unless the size were an unusually large one. The thicknesses of plates could never be expressed without fractions. But in practice it was found that a fraction of a millimetre need never be used except occasionally in fitting dimensions together, or for sheet-metal, or for wire. The committee of the British Association recommended the adoption of the centimetre and the gram because the system so based made the specific gravity coincide with the specific weight (weight per unit volume) of each substance. He submitted that

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this was no good reason. Specific gravities were of no use to engineers or any other class of practical men. Tables of specific gravity he had always looked upon as nuisances. Weights should be calculated from experiments on the heaviness of the material dealt with, and from linear measurements. For this purpose specific weights were wanted, not specific gravities. With tables of specific gravities only to go by, a double multiplication must be made where only one was needed according to any rational method. To realize the excessive uselessness of specific gravities it should be remembered that the comparison only referred to water at one particular temperature and pressure. It so happened that in the one instance, where it appeared at first sight that specific gravities might be of direct practical use, namely in the calculation of the buoyancy of ships, the specific gravity of the water to be dealt with, namely sea-water, was so far from unity that the difference could not be neglected. Specific weight was what was always practically dealt with, and the specific weight of water was certainly not the most important specific weight entering into the calculations of engineers. It was hardly used except in hydraulic engineering. In steam-engineering that of steam was of vastly more importance than that of water. He thought, therefore, that for practical purposes there need be no definite relation between the units of length and of weight or mass; and the most convenient units he had used in his own calculations were the millimetre and the kilogram.

Mr. Thursfield.

Mr. W. E. Thursfield observed that there could be no question as to the desirability of an international standard of weights and measures for engineering purposes; and, as England and America were the only two countries which still retained their old fashioned and complicated methods of arriving at arithmetical conclusions, nothing more than their common assent was necessary to give an international character to the metric and decimal systems employed by engineers on the Continent. Having had some twenty years' practical experience of the immense saving in time and labour, of the simplicity of manipulation, and of the greater accuracy obtainable by the use of the metre as the standard of all dimensions in every branch of technical work, he had great pleasure in bearing testimony to the undoubted advantages, in the several instances adduced by the Author, of the metric and decimal systems, and in supporting his arguments in favour of their adoption in place of any other. With regard to the depreciation of existing English technical literature, and of machinery, compiled and constructed in accordance with the present systems

Mr. Thursfield.

of calculation and measurement, the rapid improvements in detail, and the wear and tear of material, necessitated renewal from time to time; and the advantages to be derived by the student, as well as by the manufacturer, from the means afforded them, by an international standard of comparison, of judging the theoretical and practical results of their professional brethren in other countries, must be of more value than the loss of waste paper, and of old metal left on their hands at the end of the period of the transition. In drawing a comparison between the descent, in integral fractions, of the subdivisions of a metre, and of an inch (as quoted by the Author), Mr. Sellers appeared to have lost sight of the fact that the metre was divided into 1,000 parts, not 100; and that it was consequently capable of fourteen integral subdivisions $\frac{1}{2}, \frac{1}{4}, \frac{1}{5}, \frac{1}{8}, \frac{1}{10}, \frac{1}{20}, \frac{1}{25}, \frac{1}{40}, \frac{1}{50}, \frac{1}{100}, \frac{1}{125}, \frac{1}{250}, \frac{1}{500}, \frac{1}{1000}$, all of which could be contained on one scale; whereas, to obtain the full benefit of the inch scale, three separate forms of subdivision, or three scales were necessary, namely, the inch divided in terms of $\frac{1}{8}$, $\frac{1}{10}$, and $\frac{1}{12}$. That sizes of machinery advancing by $\frac{1}{16}$ inch were more useful and saleable, than those advancing by millimetres, was rather a matter of local prejudice, than of universal opinion. It must be immaterial to a purchaser whether the cylinders of several engines submitted for his choice had advancing diameters of $9\frac{7}{16}$ inches, $9\frac{1}{2}$ inches, and $9\frac{9}{16}$ inches, or 239 millimetres, 241 millimetres, and 243 millimetres, as the respective differences, between the latter dimensions in millimetres and the former in sixteenths of an inch, were only 0·25, 0·08 and 0·07 per cent. It would be equally correct to surmise that a fourteen-hand cob, and a sixteen-hand hunter, would be less useful and saleable if advertised at 147·5 centimetres, and 168·5 centimetres, supposing the purchaser to be intimate with the metric system. If anything, he thought the Author undervalued the saving in time by the use of the metric and decimal system in calculation; the surveyor, most expert at quantities, with the handiest of ready reckoners, would scarcely be able to work out the same number of items expressed in tons, cwts, qrs. and lbs., at x shillings per ton in one hour, as could be calculated by any one, with only a short practice in the decimal system, in three-quarters of an hour, if the weights were expressed in kilograms, and price in shillings per metre-ton; to say nothing of the increasing chance of error in proportion to the greater number of operations, and of the longer time necessary to check the results, without which the calculations were useless. With regard to the extension of the metric and decimal system to the purposes of general commerce,

Mr. Thursfield. he agreed with the Author, that the full benefit of such a step could only be reaped in conjunction with a compulsory system of decimal coinage; but, in the face of the competition of over one hundred and eighty millions of European producers, of whom one hundred and twenty millions either held, or were hungering after Colonial possession as outlets for their produce, or as standpoints from which to assail the mercantile supremacy of England, all using one standard of measure, differing from, and simpler, than the British; he thought it would be wiser, if also the mercantile world, or so much of it as would have to withstand the attack of foreign competition, were to place itself on an equal footing with its competitors, by adopting, as early as possible, their standard of mensuration.

The course of dissemination, before its adoption became compulsory, was sketched by the Author, in his reference to the method by which the change was effected in Austro-Hungary. He thought, however, his suggestions might have gone further, and that part of the burden laid on engineers might have been transferred to the shoulders of the schoolmaster. It was of no use to familiarize the workmen with a new and simpler system of measurement and calculation, if their children, who, in all human probability, were destined to take their place, were brought up in an old and complicated one. In conclusion, he agreed with the Author that practically the decimalization of the coinage was as simple, if not easier, than the conversion of weights and measures for commerce. This had been aptly illustrated in Germany, where one universal standard of monetary value had been introduced in place of the heterogeneous coinages of her numerous petty States; and in Austria, where the florin, formerly composed of 60 kreuzers, now contained 100. Yet in both countries no other change than that of nomenclature had taken place in measuring many articles of daily use. For instance, the old Krügel (0·531 litre) had become the modern $\frac{1}{2}$ litre; the old Seitel (0·353 litre) $\frac{1}{3}$ litre; the Pfiff (0·177 litre) $\frac{1}{6}$ litre. Meat and other commodities, formerly sold by the pound, were now computed by the $\frac{1}{2}$ kilogram, and so on, with, however, be it remarked, almost invariably a slight loss to the public, and a corresponding advantage to the tradesman.

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27 January, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The Discussion upon the Paper by Mr. Hamilton-Smythe on "A Comparison of British and Metric Measures for Engineering Purposes," occupied the evening.

Sect. I.—MINUTES OF PROCEEDINGS.

3 February, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Members have been transferred to the class of

Members.

Thomas Holmes Blakesley, M.A.
Josiah Corbett Bretland.
Joshua Cartwright.
Richard Swarbrick Dugdale.
Lionel Philip Payne Gallwey.
Charles Rastrick Hanson.
Joseph John Lee.
Henry Leonard Stables.
James Watson.
Guillermo White.

The following Candidates have been admitted as

Students.

Douglas Allport, Junr.
Henry Hawkshaw Carrick.
John Churchill Cartwright.
Charles Palmer Chapman.
Edward Dodd.
James William Drew.
John Dutton, Junr.
Henry Vincent Eaglesham.
Alexander Farquharson Fowler.
Sydney Sanderson Hawkins.
William Goatley Hicks.
James William Hornsby.
William Charlton Howitt.
Roger Lloyd Kennion.
Francis William Kinsey.
Sidney Cooke Lewis.
William Dorrington Boyle Little.
James Waddell Boyd Maclaren.
Marjoribanks Keppel North.
Arthur Matthews Paddon.
Arthur Carne Polwhele.
James Lennox Proudfoot.
Frank Rayner.
John Thomas Sample.
William Curwen Sheard.
Samuel Alexis Soley.
Eugene Washington Stern.

The following Candidates were balloted for and duly elected as

Members.

George Henry Bayly, B.A.
Frederick Eastment Cooper.
Paul William Dangerfield.
James Fincham.
Victorino Aurelio Lastarria.
George Lewis.
Norman Scott Russell.
Frederick Tyrrell, late Lieut.-Col. M.S.C.

Associate Members.

John Atkinson, Stud. Inst. C.E.
John Davis Barnett.
Hardinge Barrett-Lennard, Stud. Inst. C.E.
William Chatham, Stud. Inst. C.E.
Alfred Benigno Alexander Chester.
Thomas Coates.
Alfred Cockey.
Peters Chalmers Cowan, B. Sc., Stud. Inst. C.E.
Bernard Culbard.
George William Disney, Stud. Inst. C.E.
William Henry Fowler.
William Silver Hall.
Kinske Hasegawa.
Abraham Hemingway, Stud. Inst. C.E.
Arnold Frank Hills.
Harrison Hodgson.
Frank William Ward Hollands.
Norton Henry Humphrys.
Edward Fisher Jobling, Stud. Inst. C.E.
Riyosaku Kuri.
Joel Lean.
Frederick Charles Lynde.
Thomas Smith McEwen.
Alexander Marcet, Stud. Inst. C.E.
Arthur George Mumford.
John North, Stud. Inst. C.E.
Richard Oliver Ormerod, Stud. Inst. C.E.
Alfred Pearson.
Edmund Penny.
Montagu Alexis Pollard-Urquhart, Stud. Inst. C.E.
Alfred Dickinson Price, B.A.
Walter Osmond Rooper.
William Hewlett Scott.
Cecil Archibald Smith.
Charles Taylor.
Max Christian Thomson.
Charles Arrowsmith Walsh, Stud. Inst. C.E.
Harry Wray Weller.
Henry Wall Wilkinson, Stud. Inst. C.E.
George Jope Yeo.

Associate.

William Whitaker, B.A.

(*Paper No. 1983.*)

"The Modern Practice in the Construction of Steam-Boilers."

By David Salmond Smart.

The consideration of this subject will be treated under the following heads, into which it may naturally be divided:—

I. The materials used in the construction of steam-boilers.

II. Joints or seams used in the construction of steam-boilers.

III. Staying of steam-boilers, and the strengthening of internal flues.

IV. General remarks on the construction of steam-boilers.

V. Remarks on the construction of special types of boilers.

I. The Materials Used in the Construction of Steam-Boilers.

Since the manufacture of trustworthy plates of wrought iron, little else has, until a comparatively recent date, been used in the construction of steam-boilers. Within the last few years, however, mild steel has been extensively and successfully introduced. One advantage which it possesses over iron for boiler construction is its superior strength. The tensile strength of suitable steel plates varies from 26 to 30 tons per square inch; that of iron boiler-plates from 20 to 22 tons, both in the direction of the grain, showing a balance in favour of the steel of 30 to 36 per cent. Steel boilers may, on this account, be constructed considerably lighter than those of iron for a given pressure, an important advantage in some classes of work; or a higher pressure may be carried where the thickness of the plates is limited owing to the boilers being either fired externally, or otherwise subjected to the action of heated gases. Or, again, externally fired boilers of larger diameter than formerly may be, and as a matter of fact are, in considerable numbers now constructed. When the thickness of the plates, by the use of steel, is kept within moderate limits, the joints are more easily fitted, and may be more closely riveted; the different parts also are more easily bent and flanged, and better workmanship is ensured.

Other valuable properties of steel, as compared with iron, are its general superior ductility and the higher range of the limit of elasticity compared with its ultimate strength. Unfortunately, though great ductility is one of its chief excellencies, it is one in which steel is sometimes deficient, for the most part, however, only when it has been worked in the fire. Owing to the failures which have been reported in this respect, it cannot be doubted that, notwithstanding the rapidly extending use of steel in boiler-construction, there remains in most people's minds a lack of that almost implicit confidence which is felt in iron of first-class brands. Such iron, like all other iron, undoubtedly has its defects, but they are well understood and generally not of a serious nature. Much of the distrust has no doubt been caused, in the earlier days of its introduction, by the use of hard and unsuitable steel, but there is still good cause for extreme caution in the selection and testing of this material, and room for improvement in its manufacture. Many

of the failures reported have been sufficiently alarming, apparently showing that not only single plates, or batches of plates may be defective, but that local defects of a serious character sometimes exist in individual plates. When end-plates, tube-plates, and similar pieces were being flanged at one part, they would suddenly fracture in a part already finished; or, after having been successfully flanged, and even annealed, they would fracture while being afterwards worked upon. Boiler-makers, however, are now much better acquainted with the best methods of working steel, and less is heard of sudden fractures during and after flanging. It was soon found that there is less liability to fracture when a plate is entirely heated in a furnace, and the flanging carried on all round at the same time, either by hand or machine, than when it is heated and worked piecemeal at a smith's forge. When entirely heated in a furnace, local stresses, through unequal expansion and contraction, are better avoided, and there is less liability to over-heating; for there can be no doubt that a great deal of the alarm has been needlessly caused by the carelessness and ignorance of workmen in over-heating the plates. It is also a matter of experience that steel which will stand a great deal of rough usage, either at a red heat or cold, will be much injured and even break in pieces when worked at a blue heat. Few plates which have not been reheated are found deficient.

It has been observed, in the unaccountable fractures which have occurred, that there has been no reduction in thickness at their edges, clearly proving that, though the plates have been torn by internal stresses, there has been no ductility where the fractures took place; but, as has just been stated, it is likely that many more defects of this nature have been the result of over-heating or of working at too low a heat than of original deficiency in the steel. Although great care is required in reheating steel plates, those suitable for boiler-work, having great ductility and uniformity, will sustain very much more rough usage in flanging than any plates of iron, for iron plates of inferior quality have little ductility, and are easily fractured and broken, and those of the best brands are very liable to become laminated and to blister. Whether flanged from a furnace or from a smith's forge, steel plates should always be afterwards annealed.

There is a great difference between the various brands of mild steel plates in their welding properties; plates of one brand will weld readily, while those of another will break in pieces like cast iron under the hammer, and the same thing may sometimes

be said of plates from different charges of the same brand of steel.

Notwithstanding the foregoing somewhat disquieting remarks, so far as the Author is aware no accident of a serious nature has yet occurred amongst the many thousands of steel boilers now employed; nor, in the working of this vast number has anything detrimental yet presented itself of sufficient importance to check the rapidly extending use of this material. It was stated by Mr. William Parker, M. Inst. C.E., Chief Engineer Surveyor of Lloyd's Register, in a Paper[1] read before the Institution of Naval Architects in 1881, that up to the time of the failure of the steel for the boilers of the late Czar's yacht "Livadia," in 1880, no case of brittleness in mild steel plates intended for boiler-work had come under the notice of Lloyd's surveyors, out of the eleven hundred boilers of mild steel which up to that time had passed under their supervision, and general experience since then has gone to confirm the good impression.

It is a well-known fact that the tenacity, but in a much greater degree the ductility, of iron is impaired by long service in a boiler, and there can be no doubt that, under similar treatment, steel also will become somewhat deteriorated. In order to determine as far as possible whether the deterioration will be greater or less in steel than in iron, a series of experiments was recently carried out at the Cyclops Works, Sheffield, by Mr. J. F. Barnaby, and the results presented to the Controller of the Navy.[2] Samples of Siemens and Bessemer steel, of Cammell and Co.'s best boiler-iron and of Bowling iron, were subjected to repeated heating and cooling, making the conditions and temperature as nearly as possible those of portions of steam-boilers in use. Under this treatment, subsequent tests showed that both the steel and the iron sustained the tests without sensible deterioration, although in one series of experiments the specimens were heated and cooled sixty times. A further experiment was made in placing samples of the various plates under the bridge of an annealing furnace for sixteen days, in such a position that the flames could not impinge upon them, but where they were exposed during the day to a red heat, and during the night to a black heat. While undergoing this process they lost $\frac{1}{8}$ inch of thickness by scaling. When tested it was found that the steel had retained its original properties much

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[1] Transactions of the Institution of Naval Architects. Vol. xxii., p. 12.
[2] "Engineering," 20th April, 1883.

better than the iron—a fact which will no doubt afford additional encouragement to the use of steel in boiler-construction.

Steel rivets as well as steel plates are now extensively used in boiler-construction. They should not be so highly heated as iron rivets, but, as much attention in heating is not to be depended upon in the haste and carelessness of an ordinary boiler-shop with the usual fires, a special small furnace maintained at an even temperature should always be employed in heating steel rivets. There is little doubt that with continued improvement in the material, and increasing knowledge and care on the part of workmen, steel riveting for steel boilers will become the universal rule. It is carried on to a large extent in steel shipbuilding, and with growing favour. Besides the greater strength obtained, there is another consideration which renders it desirable that in steel boilers steel rivets should be employed, and not only rivets but all other parts now made of iron, and that is the prevention if possible of the corrosive action of steel on iron, which takes place under conditions favourable to corrosion when these metals are in electrical combination. All interested in this subject are indebted to the Admiralty for a most conclusive experiment which was carried out on steel and iron plates, some electrically combined and others unconnected, which were submerged for six months in Portsmouth Harbour, care having been taken, in the first place, to remove from them the oxide scale. The results of the experiment were communicated to the Institution of Naval Architects[1] in 1882 by Mr. J. Farquharson, and showed that the loss by weight of the iron plates which had been combined with steel plates was almost double the loss sustained by those which had been unconnected. The steel plates, on the other hand, which had been combined with the iron plates lost fully one-third less than those which had been uncombined. This experiment also confirmed the results of experiments previously carried out by the Admiralty and others, that under similar circumstances, and unconnected, steel suffers slightly more from corrosion than iron. The difference is so slight, however, and the superiority of steel over iron in several other respects so manifest, that the Admiralty felt justified in the substitution to a large extent of steel for iron in naval construction.

The presence of local defects in steel plates previously mentioned was further demonstrated in the experiment which has just been referred to, for the result of local electrical action in deeper

[1] Transactions of the Institution of Naval Architects. Vol. xxiii., p. 143.

blotches of corrosion was clearly observed, and Mr. Farquharson urged more care in the manufacture of steel by the proper mixture of its ingredients.

Another important matter not yet sufficiently taken into account in the construction of steel boilers is the removal of the oxide scale from the surface of the plates. It has been fully demonstrated, by experiments carried out by the Admiralty, that the oxide or scale on the surface of steel plates causes rapid corrosion of those parts which are not covered by it, more, in fact, than would be caused by similar surfaces of copper. They accordingly make it a point to remove the scale by the use of diluted hydrochloric acid or sal ammoniac, and the same process is recommended by others who have profited by their experience.

The properties and capabilities of iron with reference to boiler construction are better known than those of steel, and therefore do not require to be so fully commented on, but there is still room for a few remarks. On account of the high price, the very best brands of Yorkshire iron are now rarely used, except for plates exposed over furnaces, for parts which require severe treatment in flanging, and for rivets. The quality of iron produced by different makers varies very much, and in choosing a good brand a thorough knowledge of their relative merits is necessary. The names given to the different qualities made by individual firms are also very misleading, and many steam-users in receiving tenders for new boilers are in consequence deceived. Respectable firms of boiler-makers, of course, will not willingly deceive their customers, nor will they construct a boiler of inferior iron; but many others less scrupulous have their tenders so worded as to convey to the uninitiated a false impression. For example, a tender will undertake to provide plates of the best iron, and plates will truly be produced stamped "Best"; but the unwitting purchaser is not aware that the makers of them supply iron of much inferior quality to that of other makers of the same or other districts, and that even their best iron is not stamped "Best," but "Best Best Best," their "Best" iron being probably the lowest quality used for boiler construction, instead of the best in the market. It may be pretty well known that iron is made which is neither suited nor intended for boiler-construction, but boilers of this material nevertheless are to be found. To give an idea of the quality of much of the iron used in boiler-construction, and which is recognized as boiler-iron, it may be stated that it is not capable of being flanged, nor will boiler-makers attempt to flange it, but will provide better iron for parts requiring to be flanged. Plates

of this inferior iron, however, are punched and afterwards rolled, a very objectionable method of procedure with any quality of plates however good, but highly dangerous with those of low ductility, as they are very apt to be fractured, or at least have the fibres of the iron strained, along the line of the rivet holes of the longitudinal seams where they sharply bend in the rolls.

II. Joints or Seams used in the Construction of Steam-Boilers.

It is now well known that machine-riveting makes a closer and stronger joint than hand-riveting, and those machines which are actuated by hydraulic power, or by a combination of cranks and levers with counterbalance weights to give the required pressure, are considered better than steam-riveting machines, on account of their somewhat slower action allowing time for the rivets to fill the holes before the heads are completely formed. The plates must be fitted and well bolted together before being put into the machine, otherwise collars are apt to be formed on the rivets between the plates, thus not only preventing the joints being made tight, but also detracting much from their strength by destroying the friction between the plates. For the same reason care should be taken to remove from between the plates the bur left by drilling, and to effect this the plates require to be taken apart after being drilled. Not only the bur between the plates, but the sharp edges and burs around the holes on their outer edges should be removed, and this is now extensively done by slightly countersinking the holes. When the holes are punched these measures are not required, as the punching leaves the edges sufficiently rounded; but in that case, in order to secure tightness, the smaller ends of the holes should be kept on the inside, that is to say, that as punched holes are slightly taper, the larger ends being at the bolster side, the outer belts of plating should be punched from the inside, and the inner belts from the outside.

When the holes in punched work through defective workmanship do not come fairly opposite each other, they should be carefully widened with a rimer, and a larger size of rivets put in. Instead of this, however, a drift and heavy hammer are in most cases at once resorted to, notwithstanding all that has been said and written on the subject. Much injury is in this manner frequently done to boilers at the outset which cannot afterwards be

remedied, the holes being in many cases drawn till the overlap is strained or fractured.

The effect of punching on steel plates appears to vary much, not only with their quality but with their thickness. With regard to the thick plates used in marine work, Mr. William Parker, in the Paper already referred to, remarked, in reference to the experiments carried out with the plates of the "Livadia's" boilers after they had been rejected: "These experiments merely corroborate those already published by various authorities on the effect of punching, riming, and annealing steel plates made by either the Bessemer or the Siemens process, namely, that plates above $\frac{5}{8}$ of an inch thick punched with the largest diameter of bolster as compared with the diameter of the punch, consistent with obtaining a fair hole, lose about 30 per cent. of their tenacity, while riming out the holes, or annealing the plates after punching, restores the material to its original strength."[1] On the other hand, Prof. Alex. B. W. Kennedy, M. Inst. C.E., in the experiments carried out by him for the Institution of Mechanical Engineers, on steel plates $\frac{1}{4}$ inch and $\frac{3}{8}$ inch in thickness, found that the tenacity of the metal, between the holes in single-riveted seams, was so much increased by localizing the extension that the gain slightly exceeded the loss due to the injury done by punching. He states that the increase of tenacity due to localizing the extension, as shown by drilled plates, varied from 10·7 to 11·9 per cent., and that the increase in tenacity of the punched plates over the untouched plates varied from 1·2 to 8·4 per cent.

He further found that with plates so thin as those experimented on, a difference in the size of the bolster of $\frac{1}{16}$ inch made no appreciable difference in the strength of the plate.[2]

After the failure of the "Livadia's" boilers, punching of steel plates was for a time discountenanced, but is now again coming more into practice. Some first-class firms, however, never use a punch for steel plates; others punch small holes in the outer belts of plating only, then bolt and drill the plates together, enlarging the holes already punched, and piercing the inner plates through the solid. All plates should, where practicable, be first fitted, and then drilled together.

The strength of a joint depends much, other things remaining the same, upon the breadth of overlap, for if this be too narrow it will be the weakest part, and if too wide it will have too much

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[1] Institution of Mechanical Engineers. Proceedings. 1881, p. 215.
[2] Transactions of the Institution of Naval Architects. Vol. xxii., p. 19.

spring, and the plates will be separated by calking or fullering. The amount of overlap usually allowed in modern practice is shown by the examples given in the Appendix. Crossing the longitudinal seams, also, adds considerably to the strength of joints.

Lap-joints of thick plates have a considerably less ratio of strength, as compared to the strength of the solid plate, than those of thin plates. The strength of the joint decreases when the thickness of plate increases, owing to the greater bending action to which the thicker plates are subjected, and to their inferior ductility and flexibility. It is, therefore, preferable when thick plates are used, that the longitudinal seams should be butt-jointed and double or triple riveted with covering strips on each side. Single-riveted butt-joints with covering strips on each side are also used for some classes of work, and are stronger than double-riveted lap-joints. When butt-joints are adopted the covering strips should be cut from plates, and not from bars, and the strips for the longitudinal seams should be cut across the grain, so that when in position the fibres shall lie in the direction of the greatest stress.

Few boilers are now constructed with the longitudinal seams single-riveted. For the circular seams, however, single-riveted lap-joints are usually adopted: but in some classes of boilers which are subjected to severe strains from unequal expansion and contraction, such as marine boilers, or those of great length, it is better that the circular seams should be double riveted.

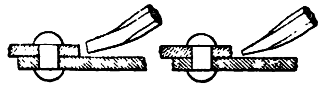
Double-riveted lap-joints for the longitudinal seams have been the usual form in land practice for many years, but they are now giving place to double-riveted butt-joints with double straps. Triple-riveted joints are also resorted to. Examples of various forms of riveted joints from the best practice are shown in the Appendix.

The longitudinal seams of the internal furnaces and flues of Lancashire and Cornish boilers are by good makers now commonly welded when of iron, and to a great extent also when of steel, which renders each ring capable of being made quite cylindrical. When steel of a brand unsuitable for welding is used for internal flues, the longitudinal seams are frequently butted with single covering strips on the fire side. Welding is also more or less employed in the longitudinal seams of the barrel portions of locomotive-boilers on the Continent; in the entire construction of some of the smaller sizes of vertical and saddle-boilers, and lately it has been successfully attempted in the longitudinal seams

of the outer shells of marine boilers when of iron. The steam-hammer is as far as possible employed in these operations.

The calking-tool for riveted joints (Fig. 2) has been, as far as possible, discarded in favour of the fullering-tool (Fig. 1). The difference between them is that the former is thin, and forms a groove, and the latter is thick, leaving the edge of the plate smooth. With the calking-tool a careless workman is more likely than with the fullering-tool to force the plates apart. Fullering of the seams, as well as planing the edges of the plates, is now generally specified for first-class work. Some firms of good reputation, relying upon well fitted joints and sound riveting, neither plane the edges of the plates on the inside of the boiler, nor fuller or calk the seams.

FIG. 1. FIG. 2.



Scale ¼.

III. Staying of Steam-Boilers, and the Strengthening Internal Flues.

There are a number of methods of staying flat surfaces, some applicable to one form of boiler, and some to another. In the Cornish, Lancashire, and kindred types, the usual method is by gusset-stays, supplemented in boilers of large diameter by a couple or more of longitudinal rod-stays. When properly designed these longitudinal stays are screwed at the ends, and secured by nuts and large washers outside and inside the boiler, but they need not be screwed through the end-plates. The ends are enlarged, so that the diameter at the bottom of the threads is a little larger than the body of the rods. In old boilers these stays are frequently found parallel throughout, the diameter over the tops of the threads being the same as that of the body of the rods. When over say 20 feet in length longitudinal stays should be supported at the middle of their length, and this is best accomplished by rods suspended from small brackets riveted to the shell. These supporting rods should not themselves pass through the boiler, otherwise the connection is almost sure sooner or later to become leaky. Such supports are necessary to maintain the stays in a straight line, else they will droop more or less, and will not take the full stress without considerable deflection of the ends. If they are to act in conjunction with gusset-stays, it would be well that they should permit of a little deflection of the ends before taking the full stress, as the gusset-stays also thus admit of some deflection,

and the stress would therefore be more equally adjusted; but in practice it is extremely difficult to allow the exact amount of deflection of the longitudinal stays which shall ensure that they take only their due amount of stress, and it is therefore better to put them in straight, supported in the middle if necessary, and to make them of sufficient strength to resist any stress which in their position can be brought to bear upon them. A short time ago, in a new boiler 30 feet long, in which the longitudinal stays were unsupported, according to the usual practice of the makers, the Author found, after the boiler had been finished ready for delivery and tested, that the stays drooped in the middle from 12 to 14 inches, and were therefore useless. If supports had been introduced this mistake could not have been made.

In some classes of work, where projecting stays would be inconvenient, the longitudinal stays have palms welded on the ends, which are secured by rivets, or fitted bolts between double angle-irons. The old system of securing them by pins to double angle-irons or $\perp$ irons is now only adopted in special cases where it is necessary that they should be removed from time to time for cleaning or examination, or for repairs. The still older plan of attaching them by saddle-plates and cotters has been entirely discontinued.

Gusset-stays are now generally secured by double angle-irons, but single angle-irons have been much used in the past. Unless in the case of small boilers, one or two of the gussets at each end on the top are usually extended and secured to the second belt of plates, the others being attached to the first belt. A space of from 8 to 9 inches is generally left between the bottom of the gussets on the end-plates and the angle-irons or flanges of the flues. This is necessary to allow for the expansion and contraction of the internal flues, and when such space is not provided and the water is in the least degree corrosive, grooving of the end-plates over the flues, or of the roots of the flanges or angle-irons, quickly results. At the same time, it should be stated that in many old boilers where the gusset-stays have been brought close down to the angle-irons of the flues, there are not the slightest signs of grooving, the water used having been entirely free from corrosive properties; and in many boilers of more recent construction, in which plenty of space has been allowed, but which, on account of the corrosive impurities of the water, has not prevented serious grooving.

In the construction of vertical multitubular boilers it is a common practice to support the tube-plates by one or more rod-

stays between the tubes. Such stays, however, do not act satisfactorily, because being surrounded by the water and steam, and not exposed to the heat of the furnace like the tubes, they do not expand to the same extent. Both tubes and stays are consequently subjected to very severe strains through unequal expansion which renders it extremely difficult to keep them tight. The same method of staying is often employed in horizontal multitubular boilers, where a similar action takes place, although to a less degree. It is less, because in the first place no portion of the tubes is exposed to the action of the heat above the water-level, and the expansion is consequently less, and secondly, in this class of boilers the tubes are generally longer and more capable of bending; but in boilers of either of these types, where stays are considered necessary, tube-stays only should be put in. Tube-stays are often inserted without being screwed through the tube-plates, but when this is done they cannot be relied upon to remain tight. They should be screwed through the tube-plates, and also be provided with nuts on the outside. Sometimes, however, the ends next the furnace are not supplied with nuts, but are only screwed through the plate, and riveted or beaded over. Only the ends of each tube-stay are screwed, but one end is enlarged, so that the hole for it in the tube-plate may admit the rest of the stay. The screw-thread on the end of each tube must be part of one continuous thread, and the same thing must be true of the tap, in order that the screw in the holes may correspond.

Screw-stays for flat surfaces, such as the sides of fire-boxes and fire-box casings of locomotive-boilers, are usually put in parallel, and screwed their entire length. Not infrequently, however, the thread is turned off between the plates, which renders them less liable to fracture, but adds to their expense. Sometimes, also, small holes are drilled in their ends to a slightly greater depth than the thickness of the plates, so that in the event of a stay breaking, warning would be immediately given by the leakage which would result. In the United States the Author has seen screw-stays, for one or two rows about the level of the fire-bars in locomotives inserted, with holes right through them, so that leakage would become apparent at whatever part of its length a stay might break. When copper fire-boxes are put in copper stays are generally used. Iron stays are usually employed with fire-boxes of iron or steel. They have the advantage over copper stays of being both cheaper and stronger, but on the other hand copper stays do not so readily become overheated, and under ordinary circumstances do not corrode. Steel screw-stays have

been perseveringly tried in locomotive practice, and are to some extent in use in the United States, but in cases which have come under the Author's notice on this side of the Atlantic, they have had to be abandoned. They are now in general use, however, for the combustion-chambers of marine-boilers, where they act satisfactorily. They are put in with nuts on the ends, or with a head on one end and a nut on the other. Similar stays are used to a considerable extent in the fire-boxes of torpedo-boat boilers of the locomotive type, but in those parts where the heat would be so intense as to destroy the nuts, the joints are riveted over in the usual way. Where practicable, nuts are preferable to riveting, as they considerably strengthen the plates. On steel stays it is better to employ a well-rounded thread than the usual V thread, as the risk of fracturing is thereby lessened; and they should never be welded nor worked in the fire. It is very desirable, on account of its superior strength, that suitable and reliable steel should be available for screw-stays for all classes of work, and there is little doubt that it will eventually be forthcoming. Screw-stays should be cut to the required length before being screwed into their places, and not screwed in on the rod, and afterwards nicked with a chisel and broken off, as is too commonly the practice, as they are thus liable to be jarred and fractured in the water-space.

Girder-stays have, until recently, been universally employed in the strengthening of fire-box crowns of the locomotive type of boilers; but direct stays between the crowns of the fire-box casings and the fire-box crowns are now to a great extent taking their place. Girder-stays are decidedly objectionable in obstructing the circulation of the water, and in tending to cause overheating through the narrow water-spaces between them and the crowns becoming choked with deposit; also on account of the severe stress thrown upon the plates on which they rest. The object in refraining from staying the crowns of the fire-box directly to the crowns of the casings has hitherto been to avoid undue strain from the greater upward expansion of the fire-box, but this objection may in a great measure be overcome, by making the crowns of the casings flat like the fire-box crowns with well rounded corners. The pressures on the two flat surfaces will nearly balance, and any unequal expansion will be taken up by the flat portions outside the stays, or by the rounded corners. The Author has seen a number of boilers constructed on this design which he believes will give perfect satisfaction. The two crowns are stayed directly to each other by bolts screwed into both, with the heads in the

fire-box and nuts on the top of the outer casing, the part in the water and steam-space being without thread. Numbers of boilers are also being made with the crowns of the casings of the usual semi-cylindrical form, and the flat fire-box crowns stayed directly to them by bolts in the manner just described, with no provision for expansion other than the spring of the plates all round. Others when thus arranged, especially when the fire-boxes are of large size, have provision for the upward expansion of the first two rows of stays over the tube-plate on getting up steam, as tube-plates have been injured by too rigid a connection.

Where girder-stays are still used they are, as a rule, forged solid, and a water-space of about 2 inches is afterwards cut out. The bosses for resting on the crown-plates, which may be rounded by machine, are tapped to receive the bolts which secure the plates. Cast-steel stays of this form are also used. It is found that by these means, instead of placing ferrules between the stays and the crowns, not only is greater rigidity obtained, but the bolts are less liable to become overheated, the heat being more readily transmitted into the stays. Commonly also in the larger class of boilers several of the girder-stays are connected by rods or links to strong angle-irons on the shell-crowns. Such angle-irons should stretch well down the sides to prevent grooving at their ends; the ends have also for the same reason been thinned away. The holes in the links are made oblong to provide for the upward expansion of the fire-box when the fires are first kindled.

It was formerly a common practice to support the flues of large Lancashire and Cornish boilers at the middle of their length by plate-stays from the shell; but these were long ago found not only to be unnecessary but highly objectionable, as they prevent the hogging movement of the flues caused by the crowns being expanded more than the bottom portions through the greater heat to which they are subjected. According to experiments mentioned by Professor Goodeve,[1] Assoc. Inst. C.E., in a boiler 28 feet long heated externally by the gases after leaving the internal flues, the upward deflection of the flues was $\frac{3}{8}$ inch, whilst when the gases were allowed to escape by the chimney after leaving the internal flues, and without heating the boiler externally, the deflection rose to $\frac{9}{16}$ inch, being greatest shortly after the fires were lighted. In view of these facts the pernicious effects of preventing the deflection by stays will be at once apparent.

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[1] "Text Book on the Steam Engine." 1879, p. 199.

In all recently constructed boilers of the Lancashire, Cornish, and kindred types, the internal flues are strengthened against collapse by flanged seams, Bowling hoops, water-tubes, or by being corrugated. The flanged seam (Fig. 3) is the invention of Mr. Daniel Adamson, M. Inst. C.E., and was applied by him as early as 1851. The Bowling hoop is the invention of the late Mr. Thomas Hill, of Heywood, near Manchester, and was introduced by him in 1861. He first bent and welded for this purpose rail iron of nearly the same section as the present hoop, which was supplied to him in straight bars by the Bowling Company, who afterwards produced the weldless hoop (Fig. 4) which bears their name. Corresponding hoops of steel are now manufactured in large quantities by the same Company and by the Bolton Iron and Steel Company. The well known Galloway tubes were the invention of Messrs. W. and J. Galloway and Sons, of Manchester, and the corrugated flues of Mr. Samson Fox, M. Inst. C.E., of the Leeds Forge Company. Instead of the Galloway tubes which are tapered, with flanges top and bottom, the bottom flange being small enough to pass through the hole required by the top end of the tube, many makers insert parallel tubes and weld them in.

FIG. 3.

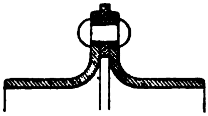

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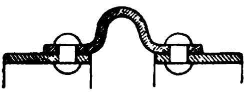
FIG. 4.



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Expansion-rings or hoops, as such, are, in the judgment of the Author, of little value, and, where the water is corrosive, what slight expansibility, or rather compressibility, they do possess is their principal disadvantage. Nothing, as a general rule, in the way of wear and tear in Lancashire and Cornish boilers sooner manifests itself than grooving of the end-plates on the water side over the crowns of the angle-irons or flanges securing the flues to the shell. This grooving is caused by the breathing action of the end-plates, due to the hogging of the flues, together with more or less corrosion from the acidity of the water. Now if the expansion of the flues is in any degree taken up by the compression of the rings, the injury will to the same extent be transferred from the end-plates to the rings, an undesirable result seeing that the end-plates can be much more easily repaired than the rings. It is a matter of experience that flanged seams or Bowling hoops do not to any great extent prevent grooving of the ends, and that in so far as they do relieve them they themselves suffer. In the case of flanged seams the grooving is most severe in the roots of the flanges attached to the end-plates when these are left unstrength-

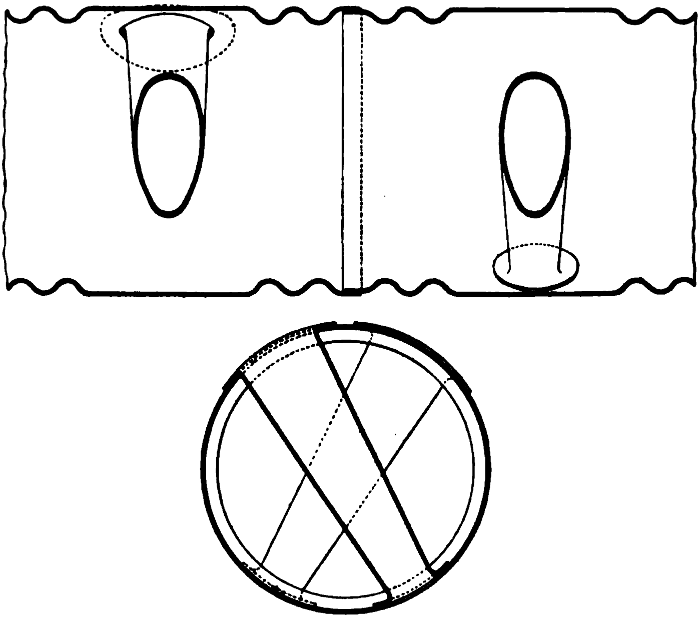
ened; but by the best makers the end-flanges are made doubly thick by having flanged pieces riveted over them on the water side, generally all round but sometimes only on the upper halves. Next to the end attachments, the flanges or hoops over the furnaces, where the hogging is greatest, suffer most. There is thus nothing to be gained in the prevention of grooving by the use of expansion-rings but a good deal to be lost, seeing that the corrosion is diverted from parts which are repaired without difficulty to those which are not. Grooving of the end-plates is easily repaired by covering strips or patches on the outside. Flanged seams, it is true, may be repaired by cutting out the defective parts and riveting on flanged pieces; but one advantage of the flanged seam over other strengthening hoops, namely, that there shall be no double thickness of plates or any rivet-heads exposed to the action of the heat is thereby lost. Bowling hoops cannot well be repaired, and others cannot be substituted without first removing one of the end-plates. Although the defects mentioned are daily to be met with under the conditions stated, and expansion rings, as such, are shown to be of little value, yet as strengthening rings they cannot be too highly commended, being indispensable with the high pressures now carried; and where the water is neither corrosive nor contains too much sediment and the firing is not excessive, either flanged seams or Bowling hoops should last as long as any boiler.

Since the introduction of corrugated furnaces and flues a few years ago they have been extensively adopted, especially in the construction of marine boilers. The special quality which recommends them is their superior strength of form, but another good feature is the somewhat greater heating surface which they expose. When first manufactured the corrugations were produced by a process which was very trying to the iron employed. The flues were first rolled plain and then swaged into shape; and there is therefore no reason to marvel that so many subsequently proved laminated and broke out in blisters. Now, however, mild steel has been substituted for iron, and new rolling-mills for the special manufacture of corrugated flues of this material have been erected by the makers, the Leeds Forge Company, by which a very superior article is turned out. As an illustration of the comparative strength of corrugated and plain flues it may be mentioned that two flues of similar dimensions and material, the one corrugated and the other plain, which had been crushed by hydraulic pressure, were exhibited by the makers at the North-East Coast Marine Exhibition in 1882. The corrugated flue had

sustained a pressure of 1,020 lbs. per square inch before giving way, while the plain flue had failed at 225 lbs.

A modification of the form of corrugated flues has been effected at the suggestion of Messrs. Hopkinson and Co. of Huddersfield, by which the adaptability of such flues for land-boilers has been considerably increased (Figs. 5). This consists in portions of the flues at regular intervals, or where desired, being left uncorrugated for the introduction of Galloway tubes, the plain parts being of the same diameter as the tops of the corrugations.

FIGS. 5.



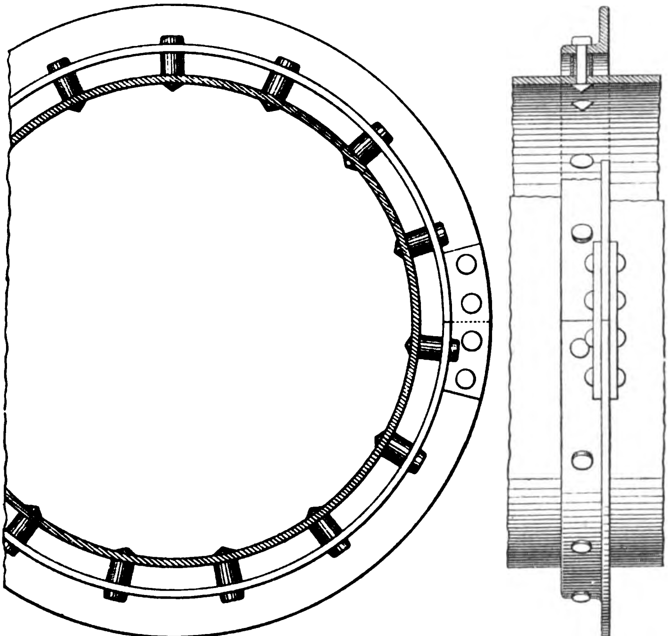
Scale $\frac{1}{12}$.

An important function of internal furnaces and flues is their action as stays in supporting the end-plates to which they are attached; but in this respect corrugated flues are inferior to plain ones, for, not only do they elongate considerably under pressure, but when overheated, as they are liable to be as well as other flues through deposit or shortness of water, they become still less able to resist the forces tending to their elongation, and may be drawn out till an undue strain is thrown upon the other supports of the end-plates, resulting probably in an explosion. To guard against such a contingency, and to prevent under ordinary conditions other

portions of the boiler being subjected to undue stress, several strong longitudinal stays should be provided close round the corrugated flues.

There are a large number of other devices in practice for strengthening flues, some of which also increase the heating surface, but they are too numerous for description here; the best only have been mentioned. By some means of strengthening, however, the internal flues of nearly all modern boilers have the power of resisting a collapsing pressure much in excess of the bursting pressure of the shells. The opposite of this formerly prevailed,

Fig. 6.



Scale $\frac{1}{12}$.

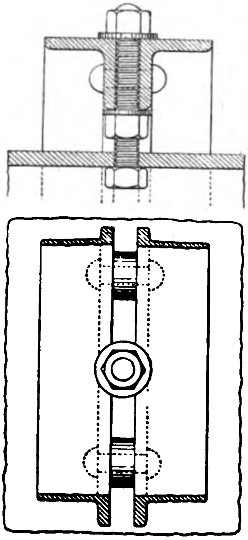
and consequently in these days of increasing pressures the question of how best to strengthen the flues of old boilers, sufficiently to utilize the full strength of the shells, is being asked on every hand. Such being the case it may not be out of place to offer a few remarks on this subject.

The simplest, least expensive, and at the same time one of the most effective plans is the fixing of one or more angle-iron hoops around each flue. As usually applied (Fig. 6) these hoops are put on with a water-space of from 1¼ inch to 1½ inch between them

and the flue, the rigidity being preserved by the insertion of ferrules through which the rivets are made to pass. The pitch of the rivets should be about 6 or 7 inches, but it is frequently much greater. In boilers of the Cornish type, where the space under the flue is limited, the rings may be put on eccentrically, with the necessary water-space at the top, but close at the bottom.

Double angle-irons and also ⊥-irons are sometimes applied, but are objectionable as usually placed on account of the increased breadth of the water-space, and the consequently greater difficulty in keeping it clear and preventing overheating. If a very strong ring is for some special purpose required, double angle-irons may be fixed, but put on inversely to the usual method (Fig. 7), that is by having the flanges parallel to the flue outside, and those perpendicular to it being turned inwards and placed back to back, not secured close together but being separated by ferrules, leaving space for the screw-stays or bolts to pass between the flanges. It will be seen that when thus arranged very little space is left where deposit may accumulate. The mistake is sometimes made of riveting angle-iron or ⊥-iron rings close to the flues without water-spaces, but unless they are at a safe distance from the furnaces—though generally speaking no distance within the length of a flue can be called safe—the double thickness of plates is extremely liable to cause overheating.

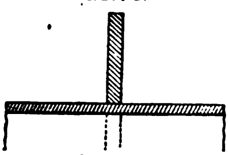
Fig. 7.



Scale ¼.

Another plan, not infrequently carried out, is to encircle the flue by a few thin rings of iron on edge, 3 inches or 4 inches in width, and about $\frac{5}{8}$-inch in thickness, closely fitted, but not attached to it (Fig. 8). This, however, is an unreliable method, and one therefore which should never be adopted; for though it may be said that before a flue can bulge inwards at any one part, it must bulge outwards at others, this will not be the case to any appreciable extent in instances of overheating for example, or of deep grooving at the longitudinal seams; and where a collapse does take place,

Fig. 8.



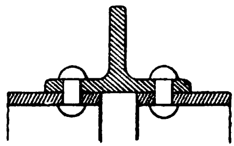
Scale ¼.

there is nothing to mitigate the extent of the accident, as in the other methods, where the plates are securely attached to the rings.

An effectual method of strengthening an old flue is by the insertion of a number of Galloway tubes, and where the flue is of sufficient diameter to allow space, after the tubes have been put in, for cleaning and inspection, this plan, but for the greater expense, is to be preferred to any other, as it also adds somewhat to the heating surface, and promotes the circulation of the water in the boiler.

Rings of ⊥ iron, made to form the connection between the plates at the circular seams (Fig. 9), have been largely employed in the past for strengthening internal flues, and form an excellent support, but they have been almost entirely superseded by flanged seams and Bowling hoops. Like Bowling hoops, they necessitate a double thickness of plates at the seams. In good water they remain intact for many years, but where the water is corrosive they give way sooner or later by the reduction and fracturing of the upper webs over the furnace-crowns. The fractures, which are radial and take place gradually, are at the same time widened by corrosion eventually giving the webs a serrated appearance like the teeth of a huge saw. The reason of the fracturing and wasting of the webs is apparent, namely, that being surrounded by water, they do not expand to the same extent as the bottom flanges, which are exposed to the heat of the furnace, and they are consequently unduly strained. As usually made for this and similar purposes, the bottom flanges of the ⊥ iron are broad enough to allow sufficient room for calking between the edges of the plates.

Fig. 9.



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IV.—General Remarks on the Construction of Steam-Boilers.

In the construction of internally-fired boilers, the plating is now universally made parallel, having an inner and an outer belt alternately, and it is thus much more easily fitted; but for externally-fired boilers, "thimble-plating" must be adopted, so that the overlaps of all the circular seams may be turned from the fire. The longitudinal seams are made to break joint as near half-plate as possible, care at the same time being taken to keep them clear of, and if possible above, the seating walls, and also clear of the gusset-stays and mountings. In steel, the plates even for

boilers of 7-feet diameter are frequently ordered in one length, and the longitudinal seams are arranged above the external flues.

Domes are not now provided, except in some instances to boilers of the locomotive type. They were formerly applied for the purpose of obtaining dry steam and for the additional steam-space which they afforded, but a perforated pipe along the top of the boiler internally forms a better steam collector, and the additional steam-space, especially in a large boiler, is so inconsiderable in proportion to the contents of the boiler, that domes may be dispensed with. Where a steam-receiver or reservoir is required, it is better to provide a separate vessel connected to the boiler by suitable necks. These steam receivers are usually horizontal, cylindrical with cambered ends. The domes in many boilers are rendered a source of weakness, on account of the openings in the shell-plates under them having been cut out the full size, and others of large diameter through having the crown-plates flat and unstrengthened. When a dome is yet thought necessary, the hole opening into it from the boiler is only made the usual size of a manhole, and the best makers also strengthen the plate by means of a strong wrought-iron ring riveted around the opening. The method of strengthening will, however, depend upon the size of the dome; the plate should not only be strong enough to resist rupture, but also stiff enough to prevent deflection; not being subjected to internal pressure alone, like the rest of the shell, it requires to be stiffened or stayed to retain it in proper form, and thus enable it to give due support to the surrounding parts. The crown of the dome itself is generally made convex.

Manhole-frames and strengthening plates were seldom met with in the earlier days of boiler-construction, but the manholes of all modern boilers from good makers are guarded either by strong cast-iron, wrought-iron, or steel frames, or by wrought-iron or steel plates. On boilers intended to work at a high pressure, the top manhole frames, which are made cylindrical with flanges at top and bottom, are usually of wrought-iron, double-riveted to the shell with a strengthening-plate on the steam side. The outer flanges of all frames should either be planed or turned to receive the covers. Cast-iron frames of this kind are now only used by the best makers on boilers intended for comparatively low pressures. Manhole-frames for the end-plates, however, which, for convenience as being more out of the way, are fitted internally, are still to a large extent made of cast-iron, though for very high pressures wrought-iron and cast-steel, which are preferable, are frequently substituted. For the smaller size of boilers, strengthen-

ing-plates around the manholes are often more convenient than frames, as the latter would sometimes prevent entrance. In small Cornish boilers it is also easier to get in when the manhole is cut elliptical, and with the longer axis in the direction of the length of the boiler as usual, but when practicable the manhole in any boiler should rather be cut with the longer axis of the ellipse transversely, as the reduction of the strength of the plate will be less.

Short stand-pipes, either of cast or wrought-iron, riveted to the plates are now provided for the mountings of all boilers, wrought-iron being used when high pressure is required. When cast-iron is used the joints are rendered tight by calking on the inside, but thin plates are sometimes inserted between the castings and the boiler, which may be calked both outside and in.

V. Remarks on the Construction of Special Types of Boilers.

Lancashire Boilers.—It is desirable in Lancashire boilers that sufficient breathing-space should not only be left between the gusset-stays and the flues, but also at the sides of the flues, between them and the shell; yet the tendency to groove at these parts is not by any means so great as over the crowns of the flues. In order to obtain the necessary space, and at the same time allow the flues to be made as large as possible, the front end-plates are usually attached by outside angle-irons. The same method cannot be adopted at the back end, as such seams if exposed to the heated gases would quickly become overheated and injured; but the back end-plates are flanged inwards or an inside angle-iron is adopted, the flanging, however, being now much preferred; and to afford sufficient breathing-space the last rings, or last two rings of plates of the flues, are reduced in diameter several inches. The first rings of plates of the furnaces at the front end are also for the same reason sometimes tapered a little towards the front. The end-plates, both of Lancashire and Cornish boilers, should either be of one piece or welded into one.

Externally-Fired Boilers.—The class of externally-fired boilers most commonly met with is the plain cylindrical horizontal, with hemispherical or cambered ends. Such boilers, though not economical, have been extensively employed for general purposes, and are yet much used at ironworks to utilize the waste heat from the various furnaces. The gases are at such places commonly made to pass only once along the boiler, the whole of the bottom half being exposed, and are then led directly to the

chimney. The heat is generally intense, and, even where there is only slight deposit from the water, fracturing of the overlaps of the seams through overheating is of constant occurrence. If the deposit is considerable, the danger is greatly increased. This, however, is not the only nor the principal evil to be guarded against. These boilers are frequently made much too long, 60 feet not being an unusual length. Under such conditions the curvature due to unequal expansion of the top and bottom plates must be extreme; the ends rising up and the centre supporting the weight. The principal danger, however, lies in the process of cooling, more especially if the boilers are emptied when hot, as is usually the case. The bottom plates are at once contracted, and often fracture through the lines of rivets of the circular seams. Such fractures are known as seam-rips.

It may be mentioned that no boiler of any description should be blown out while hot, but should first be allowed to cool down. If time cannot be found for this, cold water may be let in while the hot is being slowly run off, and the water-level kept up till the whole is gradually cooled together.

If a great length of boiler is desired for economical reasons, it is much better to construct it in two lengths, each half being complete in itself, and this is frequently done. The two lengths are connected in several different ways. Sometimes by suitable flexible pipes both in the steam and water-spaces, or by a comparatively small wrought-iron neck at the centre between the two; but probably the best method is to connect them on top by a copper pipe bent to enable it to take up the deflection, and on the bottom by a mud receiver attached to each portion by a strong wrought-iron neck of sufficient length to lower the receiver clear of the heated gases.

In externally fired boilers not only should the overlaps of the circular seams be turned away from the fire, but the longitudinal seams should be kept as far clear of it as possible.

In the case of multitubular and other flat-ended externally-fired boilers, it is important that the front end seam should be shielded from the direct impact of the heated gases by a covering of fire-bricks.

Rastrick Boilers.—The Rastrick type of boilers has been much employed for utilizing the waste heat from puddling, reheating and other furnaces, and a large number are still at work. They are vertical with hemispherical ends, and have a vertical central flue from the bottom upwards, which branches off to the sides of the shell under the water-level into two, three, or four necks. The

outer shells are generally from 25 to 30 feet high, and from 8 to 10 feet in diameter. They are surrounded by flues of brickwork below the water-level, and the heat is generally received first on the sides of the shell near the bottom, the gases thence passing up the sides, and returning downwards through the internal flue. In several respects they are not a desirable kind of boiler. For example, being externally fired, thick plates cannot be used, nor double-riveted seams, and consequently, as they are mostly of large diameter, they are unfitted for high pressure, but are ordinarily worked up to their utmost limit. They are also, owing to the method of setting, heated very unequally, the heat, which is in most cases very intense, usually striking in upon them at right angles from two, three, or four furnace-necks; the parts between the necks and also those in contact with the brickwork being of course less exposed. In consequence of the intensity of the heat being thus localized, the plates opposite the furnace-necks are constantly being overheated, fractured, and blistered, unless protected by bafflers of firebricks. A protection of this nature should always be provided for boilers heated from puddling furnaces or others giving off highly-heated gases, but through carelessness or ignorance this precaution is frequently neglected.

Vertical Boilers for Utilizing Waste Gases.—A cylindrical vertical type of boiler, with a central flue, is also much used for utilizing the waste-heat of furnaces; though not so economical, it is otherwise preferable to the Rastrick, on account of being internally fired, and therefore not subjected to the same strains through unequal expansion. In this class of boilers the gases from the furnaces are led directly to the central flue, and after passing through it, are allowed to escape at the top. Unlike the Rastrick, the shell of this boiler is capable of being made to withstand any required pressure, for as it is not subjected to the action of external heat, it may be of any thickness, and the seams may be double- or triple-riveted. The flue may be strengthened against collapse by means of encircling hoops, flanged seams, or cross water-tubes. Unless the water used, however, is moderately free from sediment or deposit, cross tubes should be left out, as they cannot in these boilers, unless under favourable circumstances, be relied upon to last very long. The circulation in them is rather imperfect, especially if placed horizontally, and consequently they get coated with deposit on the water-side and become overheated. If inserted at all, they should be placed obliquely to promote circulation through them. The bottom belt of plates of the flue should in all cases be protected by a lining of firebricks, other-

wise it will quickly become fractured and blistered, or otherwise injured by overheating. The top portion of the flue also, from a little below the water-level upwards, should be similarly protected, and for this purpose it should be enlarged so that the lining may be flush with the other plates. The bottom of the flue, however, should not be enlarged to receive the lining, as the plates immediately above it are somewhat further protected by the projecting brickwork.

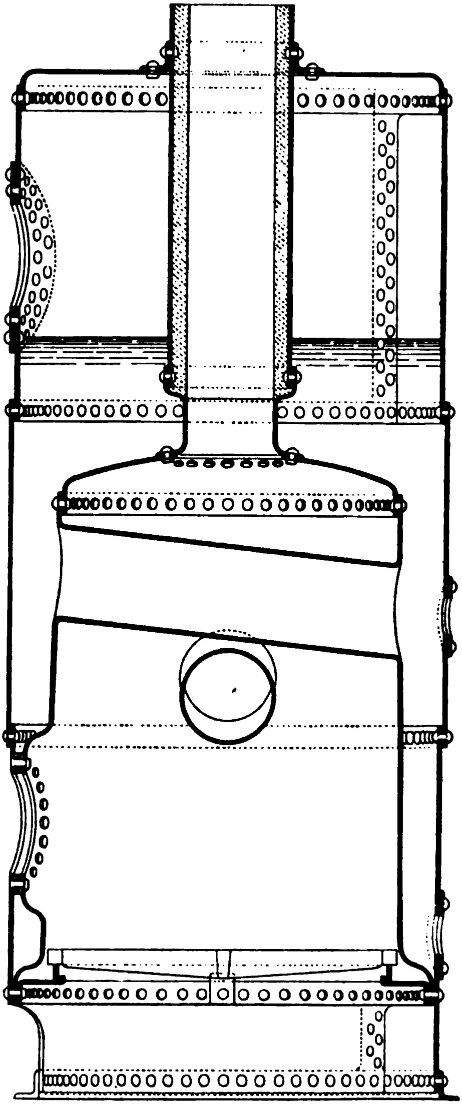
The end-plates of these boilers are generally made flat, and attached to the shell by external angle-irons. The flat plates more readily yield to the expansion of the flue than those of any other form, and may be strengthened when necessary by gusset-plates in the usual manner. An omission is frequently made in not having boilers of this class well provided internally with means of access to every part, so that they can neither be efficiently cleaned nor examined. Strong wrought-iron ladders should be fixed, or projecting steps riveted to the shell-plates, and the necessity for this will be appreciated when it is stated that these boilers are generally about 30 feet in height.

Horizontal Boilers for Utilizing Waste Heat.—This is now a more approved style of boilers for this purpose than either of the foregoing. They are merely Lancashire or Cornish boilers, and the internal flues may either be plain, or provided with a number of water-tubes. The gases are first made to pass through the internal flues, the front portions of which should be lined with fire-bricks. After leaving the internal flues, the hot gases should invariably be conducted round the outer shell, after the ordinary manner, if not for the sake of economy—often a matter considered of little consequence where the waste-heat from puddling and other furnaces is used—at least to secure equal expansion. Though of undoubted importance, it is surprising how frequently this arrangement of the flues is neglected, and the draught led directly from the internal flues to the chimney, causing endless trouble from the springing of the circular seams on the bottom, and consequent leakage and corrosion, and being absolutely dangerous with boilers of considerable length. The distinction in this respect will be easily seen between boilers of this type and vertical boilers. In the horizontal boilers the crowns are expanded by the heat of the steam, while the bottoms are comparatively cold, whilst in the vertical boilers the heat is equal all round, though greater at the top than at the bottom.

Vertical Hand-fired Boilers.—Many varieties of this class of boilers are constructed, but the kinds usually met with are those

having a single up-take flue between the crown of the fire-box and the crown of the shell (Fig. 10), and those having a number of small tubes in the corresponding position. Some remarks on the staying of the latter have been made in another part of the Paper. In the construction of the former the crowns, both of the fire-box and shell, are most frequently made convex. No doubt great strength is by this means secured, but at the expense of too great rigidity, which, by preventing the vertical expansion of the fire-box and up-take, results in grooving at the roots of the flanges of the uptake, or at the furnace crown immediately around the uptake. It is therefore better to make the crown of the shell flat, so that it may yield a little, but the crown of the fire-box should be convex, as in this form it would offer greater resistance to collapse, should it become overheated, and a slightly greater heating surface is exposed. In some of the larger

Fig. 10.



Scale $\frac{1}{48}$.

boilers of this class the up-take, from a little below the water-level upwards, is protected from the heat by a lining of fireclay, the

flue being enlarged for the purpose. Such a lining, however, should not be confined to any size of boiler, but all boilers of this type should be fitted in this manner, otherwise, owing to so much of the flue being exposed above the water-level, it must of necessity become more or less overheated. The grooving referred to is in this way accelerated, and the flue may be blistered, or rapidly corroded on the water side, or it may even collapse. Instead of a fireclay lining, some makers insert a cast-iron sleeve which fits loosely into the uptake flue. It is provided with a flange at the top for resting on the crown of the boiler, surmounted by a short neck for the reception of the funnel.

The fire-boxes of boilers of this class are usually provided with two or three cross-tubes, which not only strengthen them, but greatly increase their steaming qualities. The tubes are generally fixed horizontally, but it is better to place them with one end higher than the other, to promote circulation through them. A mud-hole is cut in the shell opposite each tube, for the removal of deposit when the boiler is cleaned. Two or three mud-holes are also provided round the bottom of the shell, so that the water-space about the level of the fire-bars may be kept free from deposit; and as this is a part where deposit is sure to settle if there be any in the boiler, the fire-bars are kept a few inches above the bottom of the water-space to prevent overheating.

The Locomotive Type of Boilers.—Besides the alteration in the methods of staying the furnace-crowns, and other points already mentioned, it may be noted that in some of the best practice in this country, and universally in the United States, locomotive shells are now constructed of steel with great success. Fire-boxes in this country are almost universally constructed of copper. Steel has been extensively tried, but has proved unreliable, and its use has been discontinued. It was found to give way, after some service, by fracturing in the manner described in a former part of this Paper. Similar difficulties have been encountered in the United States, where however steel, notwithstanding, has been found preferable either to copper or iron. Whether of copper, steel or iron, the bottom portion of the fire-box tube-plate below the tubes is reduced to the thickness of the other plates of the fire-box, which enables the necessary strength around the tubes to be maintained, and at the same time avoids undue thickness of the bottom portion at the level of the fire, which would otherwise become overheated. For the fire-boxes of portable and stationary boilers of the locomotive type, iron is the material usually employed, but both steel and copper are also used.

Brass tubes are ordinarily put in with copper fire-boxes, but for those of iron or steel, iron tubes are used. A recent improvement, practised by Mr. Stroudley, M. Inst. C.E., of the London, Brighton and South Coast Railway, is to bend all the tubes upwards in the middle of their length, by an amount equal to their own diameter, which allows them free play for expansion and contraction; and it is said that tubes so bent never leak nor give trouble in any way.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been engraved.

[APPENDIX.

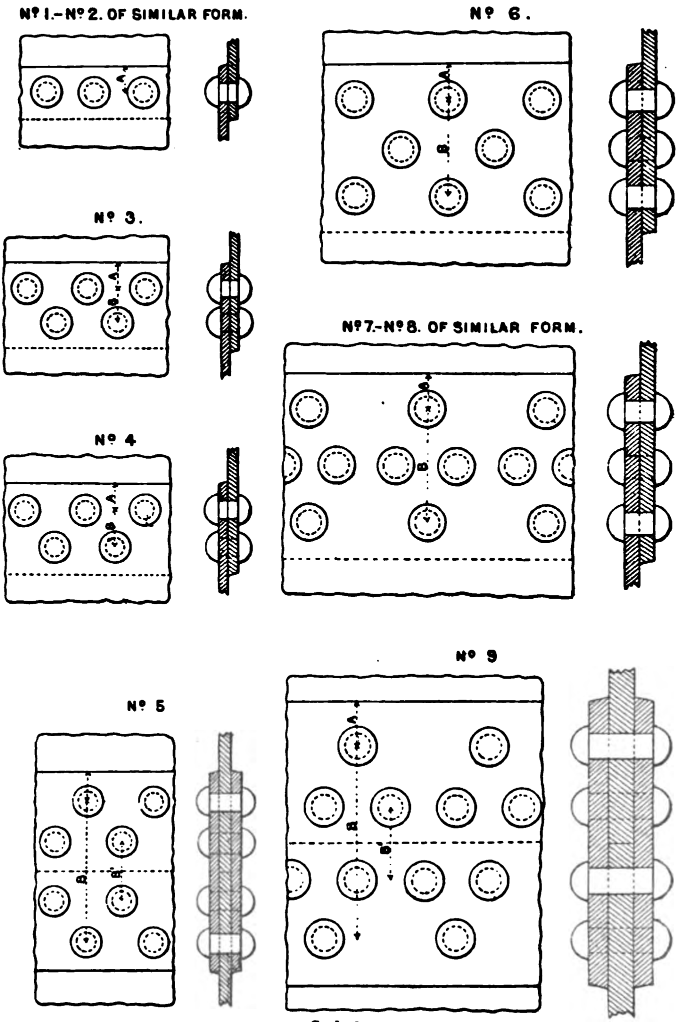
APPENDIX.—Examples of Riveted Joints.

Number of Joint.	Thickness of Plates.	Material of Plates.	How Perforated.	Diameter of Rivet Holes.	Material of Rivets.	Pitch of Outer Rows of Rivets.	Total Breadth of Overlap.	A.	B. and B[1].	Thickness of Covering Strips.	Tensile Strength of Joint in Percentage of that of Solid Plate.
	Inch.			Inch.		Inches.	Inches.	Inches.	Inches.	Inch.	
1	$\frac{3}{8}$	Iron	Punched, not annealed	$\frac{13}{16}$	Iron	2	$2\frac{1}{4}$	$1\frac{1}{8}$	..	..	43. Deduced from experiments.[1]
2	$\frac{7}{16}$	,,	,, ,, ,,	,,	,,	,,	,,	,,	..	..	40. ,, ,, [1]
3	$\frac{5}{16}$ full	Steel	Holes punched in outer belts of plates: afterwards enlarged by drilling: the inner belts drilled.	,,	,,	$2\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{1}{16}$	$1\frac{3}{8}$ full	..	68. By calculation.
4	$\frac{3}{8}$	,,	Punched, afterwards annealed.	,,	Steel	$2\frac{1}{2}$	$3\frac{13}{16}$	$1\frac{1}{8}$	$1\frac{9}{16}$	..	68. ,, ,,
5	$\frac{1}{2}$	,,	,, ,, ,,	,,	Iron	$2\frac{7}{8}$	$8\frac{1}{4}$	$1\frac{3}{16}$ scant	B. $5\frac{13}{16}$ B[1]. $2\frac{7}{16}$	$\frac{3}{8}$	72. ,, ,,
6	$\frac{5}{8}$	,,	Drilled	1	Steel	4	7	$1\frac{1}{2}$	4	..	75. ,, ,,
7	,,	,,	,, ...	,,	,,	5	$7\frac{3}{4}$	$1\frac{1}{2}$	$4\frac{3}{4}$	..	80. ,, ,,
8	$\frac{7}{8}$	,,	,, ...	$1\frac{3}{8}$	,,	$6\frac{7}{8}$	$10\frac{3}{4}$	$2\frac{1}{16}$	$6\frac{5}{8}$	..	80. ,, ,,
9	1	,,	,, ...	$1\frac{1}{8}$	,,	$5\frac{5}{8}$	$12\frac{1}{8}$	2	B. $8\frac{1}{8}$ B[1]. $3\frac{1}{8}$	$\frac{13}{16}$	80. ,, ,,

[1] Experiments by Mr. D. Kirkaldy, London, for the Boiler Insurance and Steam Power Company, Limited, Manchester. *Engineer*, Feb. 23rd, 1877.

The accompanying Table and sketches show examples of several of the best types of riveted joints in use in modern practice. In calculating the strength of the joints the tensile strength of the steel plates has been taken at 28 tons per

EXAMPLES OF RIVETED JOINTS.



Scale $\frac{1}{4}$.

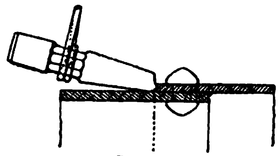
square inch; the shearing-stress of the steel rivets at 23 tons per square inch, and that of the iron rivets at 18 tons per square inch. In all the examples shown the shearing-stress of the rivets is in excess of the tensile strength of the

metal left between the rivet-holes, and it has been found that a considerable excess in this direction adds to the strength of the joint, and at the same time renders it more easily made and kept tight. As the steel plates have all been either drilled, or punched and afterwards annealed, no allowance for reduction of the strength of the metal left between the rivet-holes has been made; nor has any accession of strength been allowed for in those cases in which the holes have been drilled through the solid plates, although, as shown in the Paper, the strength of the metal left between the holes, at least in those joints with a moderately close pitch of rivets, will be somewhat increased.

Discussion.

Mr. F. W. Webb wished to say a few words about calking tools. He did not think that either of those shown by Figs. 1 and 2 was right. Both were liable to turn up the edge instead of bringing the surfaces of the plates together. The form of calking tool invariably used at Crewe was shown in Fig. 11. The calkers could never do any damage to the plate, and the surfaces were driven into close contact. He had made about thirteen hundred boilers with that form of calking-tool, and the result was that there was very little leaking. The first time steam was got up the boilers were practically "drop-tight." Another method adopted at Crewe was that of taking off the whole of the oxide from the surface of the plates before putting them together. If a seam was riveted up, and then taken to pieces again, it would be found that the scale left between the surfaces was pounded up in the form of dust. It was also found, in the preparation of the plate, that the scale got knocked off here and there; there was thus a place in which there was no scale, and that was always free for the steam to blow through, unless stopped by calking; the steam blew the dust out, and however tight the boiler might be at starting, a leak was developed after a short time. To obviate this, before he put the two parts together, he gave them a slight sponging with weak sal ammoniac and water, and those who had seen the boilers under the first test would agree with him that they were practically drop-tight as stated. The Author had referred to the effect of putting steel and iron plates together in causing corrosion. It was believed, by those who had paid a good deal of attention to the subject, that the corrosion was due in a great degree to the electric condition of the plates. If one plate was more electropositive than another, that plate was most freely attacked, and corroded away. He had tried experiments at Crewe in order to solve the question, and had used a good many tons of zinc for the purpose; in fact, for some time he had not run a single locomotive-boiler without 28 lbs. of zinc in the mud-pocket, and he had found the greatest saving from that practice. Boiler repairs on the London and North-Western Railway were getting Mr. Webb.

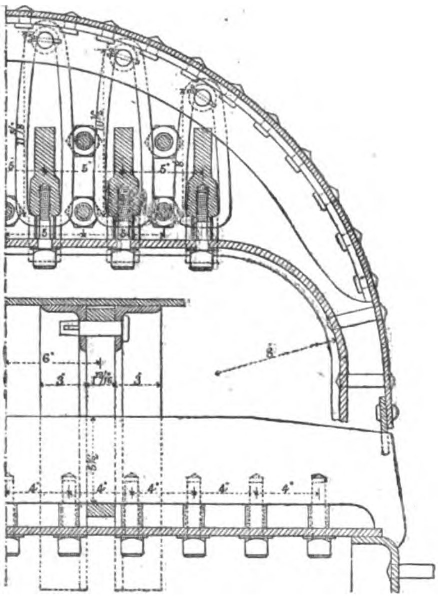
Fig. 11.



Scale ⅛.

Mr. Webb. less and less. He had been trying to wear out one engine, which he started two years and seven months ago to take an express train every day from London to Manchester and back. During that time it had run over 300,000 miles. The last time he took the tubes out, the box was getting thin, and he was obliged to put in a new one; but the boiler itself, in which zinc had been used during the whole time, was apparently as good as on the day when it went out of the shop, and he hoped to get 300,000 miles more out of it. A circular piece of zinc was put in the

Fig. 12.



Scale $\frac{1}{12}$.

mud-pocket under the barrel. The scale was of a blue colour, showing that the zinc was incorporated with it to some extent. The fire-box was of copper. He had tried steel fire-boxes for locomotives, and could go on using them, but not with commercial profit. If he were to put them in thin enough to stand, he would have to stop the boiler every few years, to introduce a new box. He believed that was found to be the case in America. The Board of Trade in England would soon interfere if he were to use split-up boxes with screwed patches in them. According to some of the American trade lists of bolts, nuts, &c., it seemed a common practice

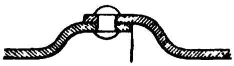
to patch fire-boxes, as special bolts for screwed patches were there advertised. The method of staying fire-boxes on the London and North-Western Railway was shown in Fig. 12. Mr. Webb.

Professor W. C. Unwin said that reference was made in the Paper to the use of collapse-rings, and credit had been given to two or three engineers in connection with them. He thought that the name of Sir W. Fairbairn ought to be mentioned, seeing that those rings grew out of the special researches made by him. The form commended by the Author was that originally adopted, and the first was made about twenty-two years ago. His opinion had been asked with regard to putting rings round the flue, without attaching them to the flue, and the subject had been mentioned in the Paper. Some engineers had the idea that if they simply made a true circular ring and slipped it on a flue, it would have the same effect as a ring riveted to the flue, and their argument was, that before the flue could collapse, it must be distorted, and as the ring prevented distortion, it prevented collapse. That was a most dangerous way of proceeding. He had seen flues collapse, and his impression was that there was no necessary distortion of the circular form previous to this taking place. He had caused glass cylinders to collapse, and there of course no distortion could occur. In the Author's observations about the placing of the material of the boiler with the fibre in the direction of the greatest strain, he ought to have restricted himself to iron, because there was nothing like the same difference in steel. Prof. Unwin.

Mr. J. N. Paxman remarked that he should have been glad to hear Mr. Webb's opinion with reference to the roof-stays of the locomotive boilers on the London and North-Western Railway. Some persons, like himself, still adhered to roof-stays. If they were properly applied with sling-stays from the circular top of the boiler they were much better than a square covering. Screw-stays for a locomotive-boiler with a square top were very difficult to get at, especially for repairing. As far as his experience went, the crown of the boiler, if provided with properly made roof-stays, did not give way; the fire-box tube-plate, the front plate, and even the side plates, would give way before the crown plate. The Author had not given any taper to the fire-box of the vertical boiler. Mr. Paxman had carried on a series of experiments in a small way, and he had found that taper fire-boxes in vertical and in locomotive boilers were a decided advantage. It was well understood that the particles of steam rising through the water accumulated when the surfaces were parallel, but with Mr. Paxman.

Mr. Paxman. a slight taper they rose vertically and did not accumulate, and the result was that priming did not take place to the same extent. There was another method of strengthening circular flues for Lancashire and Cornish boilers in addition to the forms given by the Author. This new joint (Fig. 13) was a very good one, and so far had given very good results. It greatly increased the strength of flues against collapse, whilst at the same time it was an expansion-joint, and the rivets at the junction were out of immediate contact with the fire, or, in other words, the scouring action of the flame. The flues of boilers with this joint were made of solid welded rings in steel or iron, and rolled out accurately with a machine to the shape shown in

Fig. 13.



Scale ⅛.
Expansion joint for flues.

Fig. 14.

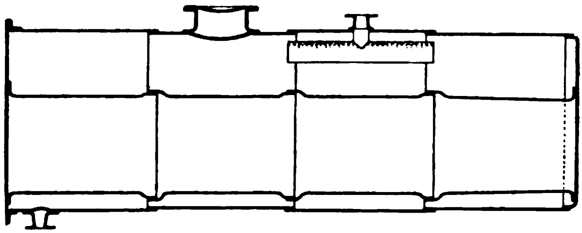


Fig. 14. They increased very slightly the cost of the boiler, whilst they added considerably to its life, strength, and flexibility.

Mr. Thornycroft. Mr. J. I. Thornycroft said the Paper dealt with boilers with large water-spaces, boilers of large volume; but the kind of boiler of which he had had the most experience was that in which a great economy of weight had been desirable; and it had therefore been necessary not only to reduce as far as possible the amount of material used, but the amount of water carried. In the construction of torpedo-boats, Messrs. Thornycroft and Co. had adopted the locomotive boiler of the short type, with a box as small as combustion could be carried on in, and when that boiler was used with a forced blast they had taxed it to its utmost power, and thus ascertained what were the defects likely to arise. They had forced the boilers until the heat of the gases seemed almost to drive the water away from the tube-plate where it joined the tubes, and as a natural consequence the tubes were often leaky. There had been several theories as to what that result depended on, whether it was due to a want of space in the fire-box or to the

supply of water to the lower part of the tube-plate. The circulation was no doubt very rapid in a locomotive boiler, but where the space was limited the circulation might be somewhat contracted, and he believed that the trouble arose from attempting to get too much heat through the tube-plate, and placing the tubes in the immediate vicinity of the fire. They had successfully surmounted that difficulty by considerably increasing the length of the box, not only in that way removing the tube-plate further from the fire, but increasing the volume and surface of the box so that part of the heat was absorbed before entering the tubes. He believed that Mr. Paxman had slung tubes within the box to take up some of the heat of the fire before it came to the tubes, but he did not know how far that contrivance had been successful. He had always been afraid of the much exposed position of those tubes, and had never attempted it. Messrs. Thornycroft and Co. had made some experiments with iron boilers in order to find out the weak points. He preferred staying the fire-box of a boiler direct to the outer box, made flat on the top with a large round corner to give elasticity. There was considerable elasticity due to this construction, so that any expansion between the case of the boiler and the fire-box was accommodated. They had constructed a number of boilers with stays in that way, and the results had been very satisfactory. With boilers of large size, where the fire-box was 7 feet long inside, the weight would be so great on the tube-plate and on the plates at the end of the fire-box as to be very dangerous, and they preferred to sling the box from the top of the boiler. The boxes and stays were of iron, and the shell of the boilers was steel. The consumption of fuel had been as much as 110 lbs. per foot of fire-grate per hour, but it was not so much as that now. Mr. Thornycroft.

Mr. Lavington E. Fletcher said there was a general impression abroad that any sort of treatment would do for a boiler, as it was only a boiler after all. Anybody could attend to it, and any place would do to put it in. Architects especially had a supreme contempt for a boiler. In erecting large buildings requiring extensive arrangements for heating and ventilating, they often overlooked the accommodation necessary for the boiler, so that when made the difficulty was to find suitable room for it, and it had to be crammed into some most inconvenient and very often dark corner. He knew many public buildings to which this remark would apply. Sometimes boilers were placed lower than the drains, and thus could not be emptied naturally. The water had to be blown out upwards with the help of steam-pressure. Mr. Fletcher.

Mr. Fletcher. Emptying boilers under steam was most objectionable. It left the brickwork, as well as the plates of the boiler, hot, and this baked on the incrustation. A boiler should be allowed to stand until the entire mass, as well as the water within, was cold, and then the water should be allowed to run out by gravitation. Contempt for boilers was the cause of nearly every explosion. If boilers were treated with the respect and consideration they deserved, explosions would be no longer heard of.

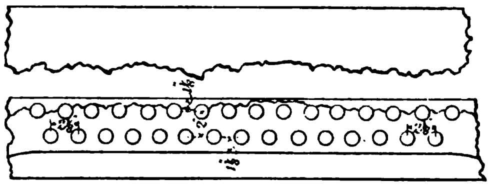
One of the most important branches of the subject of boiler construction was the quality of the material employed. Until recently boilers had generally been made of iron; but there was iron and iron, and some of it was of a very inferior character. Several explosions had occurred from this cause, reference to three of which, by way of illustration, might be made.

The first case occurred at a woollen mill at Morley, near Leeds, on the 27th of June, 1863. The boiler was of the Lancashire type, 30 feet long by 7 feet 6 inches in diameter, the thickness of the plates in the shell being $\frac{7}{16}$ inch, and the pressure 60 lbs. per square inch. The explosion was most disastrous, ten persons having been killed and the mill laid in ruins. The shell of the boiler was completely shattered, and broken up into such a number of pieces that it was difficult to trace the course of the rents. The flues were shot up in the air and thrown on to the tops of the neighbouring houses, crashing through the roofs and into the rooms below. The plates of which the shell was made were of common merchant iron. They were of the character described by boiler-makers as "pot" plates, extremely brittle, some of them breaking in pieces when merely thrown on the ground. One of the fragments, when tested, bore a strain of about 19 tons to the square inch, so that the explosion was not due to the want of tensile strength, but to the want of ductility.

The second case occurred at a dye-works at Norwich, on the 25th of September, 1866. The boiler was of the Cornish type, 20 feet long by 4 feet 6 inches in diameter, the thickness of the plates in the shell being $\frac{3}{8}$ inch, and the pressure 100 lbs. on the square inch. Though the boiler was expressly made for this pressure, it had scarcely been worked six months when it burst, killing seven persons and wrecking the works. The primary rent occurred at one of the double-riveted longitudinal seams in the shell, a portion of the rent running through the calking-line, and the remainder through the rivet-holes, as shown in Fig. 15. The plates were of Cleveland iron, and, when tested by bending, broke off short. They were quite wanting in ductility.

The third case occurred at a cotton mill at Blackburn, on the 2nd of March, 1874, when two Lancashire boilers, set side by side, blew up together, killing eleven persons and doing great havoc to the surrounding property. Two of the flue-tubes were blown upwards and thrown on to the roofs of the adjoining buildings, while many of the fragments were shot as high as the top of the mill. The shell was torn in so many pieces that it was with great difficulty that the fragments could be fitted together and Mr. Fletcher.

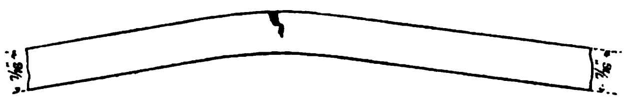
Fig. 15.



Fractured longitudinal joint in a new boiler from the use of a brittle iron plate. Norwich explosion, 25th of September, 1866.

the course of the rents unravelled. The boilers were 30 feet long by 7 feet in diameter, the thickness of the plates in the shell being $\frac{7}{16}$ inch, and the blowing-off pressure 80 lbs. per square inch. The plates were by Mr. Robert Heath, of Chatterley. On being tested by Mr. D. Kirkaldy, M. Inst. C.E., it was found that a mean of thirteen tests with the grain gave a tenacity of 18·79 tons per square inch, and an elongation of 4·1 per cent., while seventeen tests across the grain gave a tenacity of 17·6 tons per square inch, and an elongation of 2·4 per cent. Two strips, subjected to a bending test, were fractured when bent to an angle of only 15° from the straight line (Fig. 2). Two models, on which the lines

Fig. 16.



Brittle Iron Plate cut from one of the two boilers that exploded together at Blackburn on the 2nd of March, 1874. Bent cold with the grain.

of rent were marked, and also a chart of the rents in each boiler, showed how complicated the rents had been, and how entirely the shells had been broken up, which was frequently the case when plates were of a short brittle character.

Recently, on making a constructive examination of a boiler before it was removed from the maker's yard, the plates, which

Mr. Fletcher. bore the same brand as those of the two Lancashire boilers just referred to, were found to give equally unsatisfactory results, in consequence of which the boiler was condemned, and another, of more ductile plates, made instead. In a boiler of the Lancashire type, 30 feet long by 7 feet in diameter, made of plates $\frac{7}{16}$ inch thick in the shell, and worked at a pressure of 75 lbs. on the square inch, a fitting branch on the top of the shell had to be removed, to allow of the substitution of a larger one. On the removal of the old fitting branch the plate cracked, and this awakened suspicion as to the character of the material of which the boiler was made, more especially as the maker of the boiler had been tried at the Manchester Assizes, held in July 1882, for forging the trade-mark of the Low Moor Iron Company, and sentenced to three months' imprisonment. On cutting out and testing the plate, it was found to afford a tenacity of 19·9 tons per square inch with the grain, and 15·69 tons across the grain, but not to elongate in either case. On submitting the plates to a bending test a fracture occurred, as illustrated in Fig. 17,

FIG. 17.

Brittle Iron Plate cut from a boiler in work. Bent cold with the grain. Boiler condemned and taken out.

at a very slight departure from the straight line, showing that the plates were of a short brittle character, quite unfit for use in a boiler. In consequence of these tests the boiler was condemned and taken out.

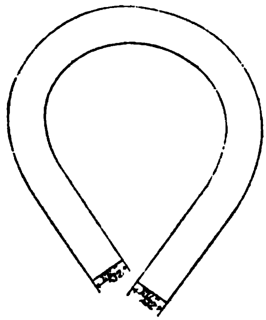
Turning from the consideration of brittle plates to ductile ones, Mr. Fletcher then proceeded to show some specimens of Snedshill and Monk Bridge plates, which had bent cold, without cracking, to a curve having a radius of three or four times the thickness of the test strip (Fig. 18).

The foregoing showed that in the construction of boilers it was most dangerous to employ plates of a short brittle character, and demonstrated the necessity of testing the quality of the plates before they were used. Ductility was of more importance than a high tensile power.

With regard to the use of steel plates for boilers, in the early days of the manufacture of steel some of the plates used, though possessing a high tensile power, were short and brittle. One or

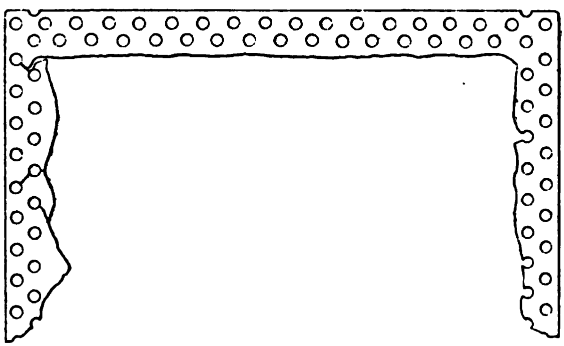
two cases of this description had come under his observation. Mr. Fletcher.
A boiler, of the internally-fired multitubular type, made in 1861, 6 feet 6 inches in diameter, double-riveted at the longitudinal, as well as at the circumferential seams, $\frac{1}{2}$ inch thick in the shell, and worked at a pressure of 65 lbs. on the square inch, was one of a range of six of similar construction in a cotton mill, having been turned out by a first-class boiler-maker. After working fifteen or sixteen years, it was taken out for the substitution of another boiler, adapted to carry a pressure of 100 lbs. on the square inch. When removed it was re-set at another works and tested by hydraulic pressure, and although it had previously worked at a pressure of 65 lbs. on the square inch, and had been made for one of 80 lbs., it burst under the hydraulic test at a pressure of 112 lbs., the rent occurring in the shell, and running longitudinally across the entire width of one of the belts of plating, as nearly as might be, not through the rivet-holes, but

FIG. 18.



Ductile Iron Plate bent cold with the grain to test the quality. Approved.

FIG. 19.



Longitudinal Fracture which occurred in a Boiler under hydraulic test at 112 lbs. pressure per square inch, though the Boiler had been made for 80 lbs. and worked for years at 65 lbs. Plate of Bessemer steel.

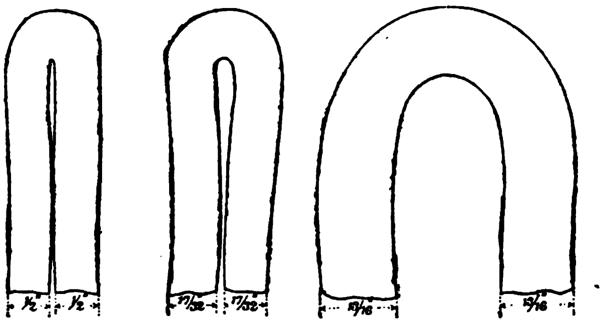
through the solid metal at the calking line at the edge of the overlap (Fig. 19). There was not the slightest sign of fibre. Had the rent occurred when the boiler was under steam, a serious explosion must have resulted. Another case, somewhat similar, had come to his knowledge. Two new boilers of the Lancashire

Mr. Fletcher. type, 7 feet in diameter, were being tested on the maker's premises by hydraulic pressure. These boilers were to work at 100 lbs. on the square inch, but when the test pressure reached 130 lbs. both of them burst, the rent occurring through the cast-iron fitting branch for the low-water safety-valve. These fractures showed not only that boiler-plates when of steel should be of mild ductile quality, though at the expense somewhat of tensile power, but also that all fitting branches should be of wrought instead of cast iron. Some leading boiler-makers, however, insisted on making fitting branches of cast iron for boilers working at as high a pressure as 80 lbs. on the inch. This was highly objectionable. The three boilers just referred to were of Bessemer steel.

Great improvement, however, had been made in the manufacture of steel since then, and the mild steel now adopted was far more ductile and reliable. Steel-plate makers adopted a complete system of testing, which was of great importance. Every plate was sheared on its four sides, and one of the shearing strips from every plate was tested by bending, while, in addition, several strips from every charge were pulled asunder in a testing machine. Further, boiler-makers were now laying down their own testing-machines, by means of which they checked the tests made by the makers of the plates. In the neighbourhood of Manchester, Messrs. D. Adamson and Co., Mr. Thomas Beeley, and Messrs. Galloway, had their own testing-machines, and he thought it would be well for other boiler-makers to follow their example. The practice adopted by the Manchester Steam Users Association, when making constructive examinations of new boilers, was to take strips in duplicate from the pieces of plate cut out for the manhole, the steam stop-valve, the blow-out valve, and the two safety-valves. One of each pair of strips was submitted to a temper test. It was heated to a low cherry red, then cooled in water, at a temperature of about 80°, and doubled back, when it was expected to bend to a curve having an inner radius of not more than one and a half time its own thickness without cracking. The other strip was a reserve, and was bent, sometimes tempered and sometimes untempered. Also tensile tests were made, both for ductility and tenacity. Fig. 20 illustrated the shape assumed by the steel strips when bent cold, after being tempered without cracking. One of the specimens was of Dalzell steel, Motherwell, another of Hallside, Glasgow, and the third of Sir John Brown and Co., Sheffield, while a list of the tensile strengths was given below. In each case the steel was made by the Martins-Siemens process.

Mr. Fletcher.

FIGS. 20.



Mild Steel Plates bent cold with the grain after tempering.

The following were the results of some of the tensile tests:—

Test.	Dalzell Steel. Tenacity per Sq. Inch.	Dalzell Steel. Elongation in 10 inches.	Bolton Steel. Tenacity per Sq. Inch.	Bolton Steel. Elongation in 8 inches.
	Tons.	Per Cent.	Tons.	Per Cent.
1	27·901	29·00	26·62	29·680
2	28·348	25·00	27·54	28·125
3	28·125	27·50	..	..
4	26·785	26·00	..	..
Mean	27·789	26·87	27·08	28·902

Test.	Sir John Brown and Co.'s Steel. Tenacity per Square Inch.	Sir John Brown and Co.'s Steel. Elongation in 10 inches.	Hallside Steel. Tenacity per Square Inch.	Hallside Steel. Elongation in 8 inches.
	Tons.	Per Cent.	Tons.	Per Cent.
1	29·149	22·500	29·00	20·00
2	28·020	23·125	27·90	25·00
3	28·120	26·875	27·90	25·00
4	27·750	26·875	27·10	21·50
5	27·580	23·250	28·60	24·20
6	27·880	26·250	28·60	24·60
7	27·880	25·000	29·50	23·00
8	27·350	27·500	29·80	23·40
9	26·470	23·875	28·20	21·00
10	29·000	25·625	29·70	26·50
11	26·970	28·750	..	..
12	27·041	23·875	..	..
13	27·100	27·500	..	..
14	27·180	28·125	..	..
15	28·260	25·000	..	..
16	27·160	28·125	..	..
17	26·990	23·125	..	..
Mean	27·641	25·610	28·63	23·42

Mr. Fletcher. Iron plates were never tested as steel plates were now. For boiler purposes, steel seemed likely to supersede iron altogether. The plates could be thinner in steel than in iron, with the same pressure and the same diameter of boiler, while the cost of steel was less than of iron plates.

Mr. Fletcher wished, however, to give one warning as to the use of steel. It needed careful handling with regard to heating. He had some strips which had broken off as short as a piece of crockery-ware, though they were of the same steel, of the same size, and had been treated in the same way as those which had doubled back without fracture. In preparation for the temper test, these strips had been heated in a smith's fire, but after the fractures one of the broken specimens had been put into an oven, baked through, and then tempered, when it bent as kindly as the others; so that the difference in the behaviour of the two parts of the same strip appeared to be due to the mode of heating, the strip having been heated unequally in the first case, and equally in the second. That seemed to convey a rather important lesson. He thought it advisable to avoid thinning the corners of plates for the shells of boilers by forging, which involved heating, and either to plane them down, or, better still, to make a butt joint with two cover strips, the one inside and the other out, when the plates would be bent round cold just as they came from the makers, and would not be heated at all. The recommendation, however, to roll the steel plates of boilers cold might be generally applicable to those required for land boilers, but not to those now in use for marine boilers, on account of the excessive thickness. Difficulty had been found to result from passing these thick plates through the bending rolls when hot, from the heating not having been regular throughout, one part of the plate being hotter than the other. From this cause a marine boiler 13 feet in diameter and 16 feet long, designed for a pressure of 150 lbs. on the square inch, recently burst under the hydraulic test when the pressure was brought up to 240 lbs.[1]

To revert to the cover-strip, this would have to be heated so as to be brought to the sweep of the boiler, but it could be baked in an oven-furnace, and thus heated all over and equally. If thinned at the ends for tucking under the outer belts of plating, it should be annealed after forging, though it would be better to thin by planing, or to butt the ends of the cover-strip against the adjoining plates, when thinning would not be necessary.

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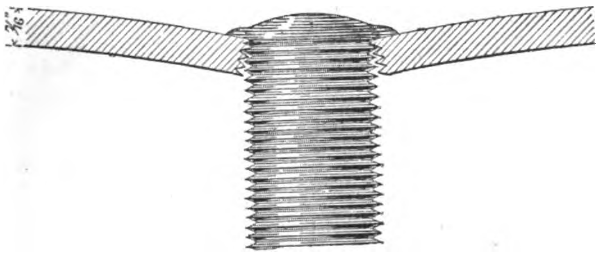
[1] "Experience in the use of thick Steel Boiler Plates," by W. Parker, Transactions of the Institution of Naval Architects. Vol. xxvi.

Mr. Fletcher.

Reference had been made in the Paper to stays. The Author recommended that the longitudinal bolt-stays in Lancashire boilers, which extended from one end of the boiler to the other, should be supported in the middle of their length when more than 20 feet long. It was most important that these longitudinal bolt-stays should afford elasticity. If they were screwed up too tight, they would set the boilers leaking. The stays should be allowed to have sufficient play to sag 2 or 3 inches, so that they could be swung backwards and forwards horizontally by the hand some 4 or 6 inches. They should be ready to come to the rescue when wanted, and not be brought into action till then; otherwise re-actions would be set up between the various parts of the boiler, leading to great mischief.

Screwed stud-stays had an attribute which was not perhaps generally known, which was, that unless they were nutted they had been found to pull through the plate without destroying the

Fig. 21.



Screwed Stud-stay escaping from the plate without stripping the thread.

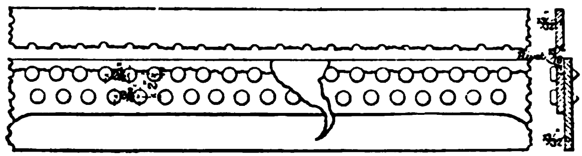
thread. When the stay pulled through the plate, the natural conclusion was that the thread had been stripped; but that was not the case. The pressure on the flat plate bulged it, and thus enlarged the hole, relieved the thread, and allowed the stay to escape, as shown in Fig. 21.

In investigating the explosion which occurred on board H.M.S. "Thunderer," on the 14th of July 1876, an experimental chamber was made at Portsmouth, and when hydraulic pressure was applied, the screwed stud-stays slipped through the plate, to the surprise of the observers, the thread suffering but little damage. This attribute of screwed stud-stays when not nutted was new to him, and perhaps to others at that time; but it was known and had been published by Professor R. H. Thurston, of New Jersey.[1]

[1] The Journal of the Franklin Institute. 1872, 3rd Series, vol. lxiii., p. 97.

Mr. Fletcher. Another point in boiler-making had not received sufficient attention, namely, the mode in which the plates for the cylindrical shell were bent. In bending the plates to the sweep of the shell, they were passed between rolls; but as these rolls were sometimes arranged, the plates were not rendered circular throughout, but a flat portion, a few inches wide, was left at the end. To bring this up to the circle, the plates were flogged with sledge-hammers. Of course the plate would yield at the weakest point, and if the rivet-holes were made when the plates were flat, as used to be the general practice, and there were two rows, the plate was likely to crack at the inner line of holes. This crack might not penetrate all through the plate, and therefore might not be discernible when the boiler was put together, as when it occurred on the inner overlap it lurked concealed between the two plates. No. 60 Board of Trade Report, under the Boiler Explosions Act, treated of an explosion that occurred at Bristol on the 23rd of November 1883. In this report was shown a crack of the kind just described (Fig. 22)

FIG. 22.



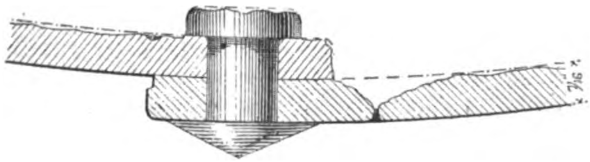
Fractured Longitudinal Joint, from a concealed crack lurking between the overlaps penetrating half way through the plate, and running from rivet-hole to rivet-hole. Plate of iron. Bristol explosion, 23rd of November, 1883.

running from rivet-hole to rivet-hole, and penetrating about half-way through the plate. There it remained snugly out of sight and unsuspected for six or seven years, when, without any warning, the boiler burst. No inspection could have detected it after the work was put together.

With regard to grooving, this was not, as a rule, dangerous in Lancashire boilers, the diameter of the shells being so large, and the curve so easy that grooving did not occur in the cylindrical portion, though it did occur in the flat ends, where it was not of much importance in respect to safety. In the barrels of locomotive boilers, however, in which the diameter was smaller and the curve consequently quicker, grooves frequently occurred, and these became dangerous. They were internal, and occurred at the overlaps of the longitudinal seams of rivets. Fig. 23 represented their general shape.

A locomotive-boiler explosion occurred from this cause, on the 4th of July, 1861, on the London and North-Western Railway at Rugby, just as the Irish mail-train was leaving the station. From that time up to the 26th of December, 1881, the Manchester Steam Users Association had recorded sixty-six locomotive-boiler explosions. Many of these explosions, though not all, arose from internal grooves of the general shape shown in Fig. 23. Recently, however, grooves had been met with of a very different shape. Mr. Fletcher.

FIG. 23.

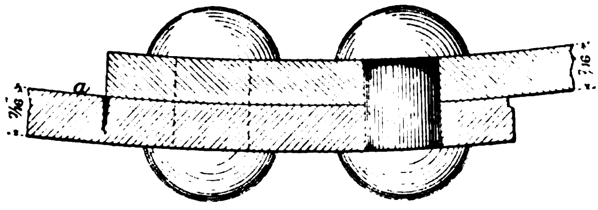


Ordinary Locomotive Groove at a longitudinal seam of rivets. Plate of iron.

Instead of being open, with a contained angle of about 120°, they had closed up. They resembled a saw-cut, or fine nick, close to the over-lap of the plate, and were thus very difficult of detection. (*a* Fig. 24.)

On the North-Eastern Railway three explosions had arisen from these fine nicks, one on the 24th of November, 1878; a second on the 26th of January, 1880, and a third on the 12th of November,

FIG. 24.



Fine-nick Locomotive Groove *a* at a longitudinal seam of rivets. Plate of iron.

1880. The Locomotive Superintendent being desirous to investigate the matter, cut up a twin boiler to the one that exploded on the 26th of January, 1880. This boiler had not been suspected of having anything wrong about it, but on examining the seams of rivets, and on bending the plates back, a fine nick was discovered penetrating nearly through it, and much endangering the safety of the boiler. The plates were of Low Moor iron, and the boilers had been turned out by good makers, two by Messrs. Robert Stephenson and Co., of Newcastle-on-Tyne, and the other by

Mr. Fletcher. Messrs. Walter Neilson and Co., of Glasgow. Another locomotive-boiler explosion from a similar cause occurred on the 5th of July, 1884, on the North British Railway, at Balloch Station, near Dumbarton. Through the courtesy of the Locomotive-Superintendent he had been enabled to examine the exploded boiler, when he found that the nick-groove at which the primary rent had occurred, instead of being below the water-line, as was usually the case, was at the top of the barrel of the boiler in the steam space. The plates were of Farnley iron, and when tested afforded a tenacity of 21·59 tons per square inch, and an elongation of 6·25 per cent. in a length of 8 inches. Thus the rate of elongation was not very high. He thought it desirable that locomotive engineers should turn their attention to these fine nicks. It appeared to him, though he was not prepared to speak positively, that the wide open grooves appertained to single riveting, and the fine nicks to double riveting. He did not wish, however, to recommend single instead of double riveting, but thought the occurrence of these nicks afforded an argument in favour of adopting the butt-joint with double cover-strips, one inside and the other out, for the barrels of locomotive-boilers, so as to ensure the true cylindrical shape.

External firing was not equal to internal firing either on the score of safety or economy. In illustration of this the explosion at Bilston on the 5th of November, 1884, might be referred to, when three boilers in a range of eight of plain cylindrical egg-ended construction externally fired blew up together, killing three men and wrecking the works, the fragments being thrown to great distances. The explosion was due to overheating of the plates through shortness of water. Had the boilers been of the internally-fired type the injury to the boiler would have been confined to the furnace-crown. That would have collapsed and have been rent, when a torrent of steam and hot water would have rushed out at the furnace-mouth; but, judging from other cases, the boiler would not have been disturbed from its seat, the works would not have been wrecked nor would any one have been scalded unless standing just in front of the boiler and in the line of fire.

Although multiple explosions had arisen from internally-fired boilers they were only occasional, and not by any means so frequent as those from boilers fired externally. Seven multiple explosions from plain cylindrical externally-fired boilers had been recorded by the Manchester Steam Users Association. The first of these occurred on the 21st of February, 1862, at Fenton Park Ironworks, when three boilers blew up together, killing one person;

the second occurred on the 8th of April, 1863, at Mossend Ironworks, Glasgow, when five boilers blew up together, killing nine persons; the third on the 17th of February, 1864, at Aberaman Ironworks, South Wales, when two boilers blew up together, killing thirteen persons; the fourth on the 15th of January, 1871, at Blair Ironworks, Dalry, Ayrshire, when two boilers blew up together; the fifth on the 18th of February, 1872, at St. Helens, when three boilers blew up together, killing four persons; the sixth on the 19th of March, 1879, at Coltness, when six boilers blew up together, killing one person; and the seventh on the 20th of November, 1880, at Ruabon, when two boilers blew up together, killing six persons. It was most inexpedient to set a battery of plain cylindrical externally-fired boilers so as to cover a busy works. Should they explode the flight of the fragments would play serious havoc both with life and property. If plain cylindrical externally-fired boilers were adopted at all, the ends should be lashed together with strong longitudinal tie-bolts to prevent their flying asunder when the boiler failed at the ring seam of rivets, as it was so prone to do. Mr. Fletcher.

Three cases had been met with in which internally-fired boilers had given rise to multiple explosions. The first of these occurred on the 1st of November, 1866, on board a steam-tug at the Hotwells, Bristol, when two boilers of the flue-marine type blew up together, sinking the tug and killing five persons; the second, already referred to while treating on the danger of using plates for boilers of a short brittle character, occurred on the 2nd of March, 1874, at a cotton-mill at Blackburn, when two boilers of the Lancashire type blew up together, killing eleven persons; the third occurred at Pendleton, on the 27th of March, 1876, when two boilers burst, killing one person. The last case was somewhat peculiar. The boiler that burst primarily was of the "Galloway" type, and gave way in the shell from thinning through external corrosion. The boiler alongside that burst secondarily was of Barber's patent, in which the furnaces, instead of passing to the back of the boiler and thus tying the two ends together, turned abruptly down and passed out through the bottom of the shell, making an opening about 3 feet in diameter. Through this opening the boiler parted, the rent running round the shell at a ring-seam of rivets. Thus the boiler had lost the longitudinal tie afforded by the internal tubes in Lancashire boilers, and it behaved just as a plain cylindrical externally-fired boiler was frequently found to do, tearing in two at a ring-seam of rivets. Had this boiler been of the Lancashire type it was doubtful if there would have been a multiple explo-

Mr. Fletcher. sion. Although multiple explosions were less frequent from internally-fired boilers than from those fired externally, yet the above showed that internally-fired boilers were not altogether free from them; and, having regard to the high pressures, and the large diameters now adopted, it was evident that the greatest attention must be paid to the quality of the material as well as to the quality of the workmanship; or should one such boiler in a range burst it was to be feared that it might lead to the bursting of one or more of those alongside.

Vertical internally-fired boilers now so commonly used for cranes, winches, and many miscellaneous purposes did not prove as strong in fact as they appeared on paper. The shells were, as a rule, of such small diameter, and the furnace-tubes so short, that it might be supposed they would withstand with safety a high pressure. A great number of explosions, however, had arisen from these boilers, as would be seen on reference to the Board of Trade Reports under the Boiler Explosions Act 1882. Many had failed through collapse of the fire-box although strengthened with cross water-pipes. The water space around the fire-box in these boilers was frequently too narrow. It should not be less than 2½ inches or 3 inches wide at the bottom, and 6 inches at the top for a fire-box 4 or 5 feet high; inasmuch as in this space the steam had to ascend and the water to descend, while sediment tended to lodge there. In many cases it was wise to strengthen the sides of the fire-box by tying them to the sides of the shell by means of screwed stud-stays. In these boilers there was a strong upward thrust, and when the crown of the shell was domed and the crown of the fire-box domed also, the structure was too rigid. There was no room for expansion, and the smoke-pipe rapidly became grooved at its attachment to the fire-box crown. The top of the shell should be flat, to allow of an upward movement, but it might be stayed with gussets if required. Vertical bolt-stays had been recommended by the Board of Trade to tie the crown of the fire-box to the crown of the shell, and several explosions which had occurred showed that they would have been of service. These vertical bolt-stays might in many cases be useful adjuncts, but it was thought that the boiler should be so constructed as not to require them.

In conclusion, Mr. Fletcher expressed a hope that increased attention would be paid to boiler construction; and he urged the importance of adopting the best material as well as the best workmanship, and of keeping up the standard. Boilers should be got up as well as a first-class piece of engine work.

Professor Kennedy.

Professor ALEXANDER B. W. KENNEDY said that as the Author had referred to some experiments of his, and Mr. Fletcher to a point on which he had made some tests, he should be glad to say a few words respecting them. The experiments in question had been made for the Institution of Mechanical Engineers with thin boiler plates of Landore steel punched, in which he found that the strength of the plate after punching remained as great as it was before, but not as great as the same plate would have had had it been drilled. The plates were of a very soft quality of mild steel. He had not further experimented upon that point, but he had often noticed in pieces that had been sent to him for testing, bearing somewhat injudiciously a large inspector's-mark in the centre of the piece, that if the material were wrought iron it more commonly broke at that mark than if it were of steel. The nicking might have been, of course, in the wrought iron a nicking through certain fibres, and in the steel a mere pressing down of the outside of the metal. However, the latter material did not seem to give way as might have been expected under the circumstances. With reference to the excess of resistance of a plate when it had been drilled over the resistance of the same plate before any holes had been made in it, since the experiments cited by the Author, Professor Kennedy had made many others extending to plate $\frac{3}{4}$-inch thick, and he had found that exactly the same thing held good. In cases of double-riveted lap-joints, for example, with $\frac{3}{4}$-inch plates and $1\frac{1}{10}$-inch rivets pitched nearly three diameters apart, there was an excess of tenacity of 8 per cent., and still more with thinner plate; this was, as comparing the resistance of the net area between the rivets with the strength of the plate before anything had been done to it. That seemed to appear only in the case of very soft material, but it had to be taken into account in designing a thoroughly good joint with steel plates and steel rivets. Another matter, which had not always received sufficient attention, had been the allowing of sufficient diagonal area measured zigzag between the rivets. He had made many experiments upon that point, and felt justified in saying that unless the strength of the joint was to be under what it should otherwise be, the area of the plate measured zigzag should be at least 30 per cent. in excess of the area measured straight across; if less than that it was likely that the joint would break zigzag, and at a lower pressure, than it would otherwise do. He had found 30 per cent. and 35 per cent. of excess to produce joints in $\frac{3}{4}$-inch plate which would be equally likely to give way by shearing the rivets or tearing the plate. With reference to Mr. Fletcher's remarks on the subject of double butt

Professor Kennedy.

strips, he was afraid it was not always known how dangerous joints with single butt strips might be. He had had a joint brought to him from an air-vessel which burst some years ago, which had been made of perfectly good $\frac{3}{8}$-inch iron, jointed with a single strip put on outside. The strip, a $\frac{3}{8}$-inch plate or bar (he did not know which), was 6 inches broad. This strip was, of course, pulled across its grain. The tenacity of a strip or bar 6 inches wide across the grain was not very great, and it did not appear to have been taken into account in that case; but the water had found its way in between the edges of the plates, and then to the outside of the plates under the butt strip, so that when the joints broke they did not break through the rivet-holes, but across the butt strip, where its want of transverse strength, and the corrosion, had made it so weak, that a joint 6 inches broad and $\frac{3}{8}$-inch thick broke in one case under 4 tons total pull, or $\frac{2}{3}$ ton per inch in breadth. He gave the following short Table, referring to experiments made for the Institution of Mechanical Engineers, as illustrating the points he had mentioned[1] :—

Type of Joint.	Thickness of Plate.	Diameter of Rivets.	Ratio of Pitch to Diameter.	Excess of Diagonal Area.	Excess Tenacity of Plates.	Efficiency of Joint.	Remarks.
	Inch.	Inch.		Per cent.	Per cent.	Per cent.	
Double riveted lap	$\frac{3}{8}$	0·8	3·62	29	10·0	80	Joints of equal strength in plate and rivets.
„ „ butt	„	0·7	3·93	27	6·6	80	
„ „ lap	$\frac{3}{4}$	1·1	2·82	35	7·8	70	Do. Do.
„ „ butt	„	1·1	4·0	26	loss 8	69	In this case the plates turned out to be hard and somewhat crystallizing, and the edges beyond the rivets were unavoidably narrow.

In all cases both plates and rivets were of soft steel, and the rivet-holes drilled to the diameters given.

Mr. Farquharson.

Mr. J. FARQUHARSON observed that the Author had referred to some experiments which he had conducted for the Admiralty on several kinds of steel. Those experiments, instead of extending only over six months, had extended over five periods of six months

[1] Institution of Mechanical Engineers. Proceedings 1881, p. 205.

each, and they were conducted for different purposes. Before referring to them he would state what were the Admiralty tests for steel for boiler-purposes. "(1) Strips 1½-inch wide cut by a planing-machine lengthwise or crosswise from the plate must stand a tensile strain of not less than 26 tons or more than 30 tons per square inch, and have a stretch of not less than 20 per cent. on a length of 8 inches. (2) Strips of the size and cut as described above, heated to a low cherry red and cooled in water at 82° Fahrenheit, must stand bending in a press to a curve the inner radius of which is one and a half times the thickness of the plate. (3) One or both the above tests to be applied to every plate. (4) All plates to be free from lamination and other surface defects." There was very little difficulty in carrying out those requirements because the Admiralty had resident inspectors at all the places where steel was made. Steel rivets were used exclusively for steel work, whether for boilers or ships, and the Admiralty now employed steel alone for all plates of ships and angles; all work being riveted with steel. One rivet in every hundred was tested, and it was required to be able to bend cold, without fracture, to a radius equal to the diameter of the rivet, and to be able to bend hot close on itself without fracture, after being subjected to heating and chilling in the way before described. The inference he drew from those tests was that the Admiralty did not show any great amount of trust in steel as at present produced. In the experiments, to which reference had been made in the Paper, one of the objects in view was to ascertain the corrosive effect of the surface oxide on steel. It was found to be about the same as on an equal area of copper. One outcome of the experiments was that the Admiralty now removed oxide from the surface of plates entirely, and it disclosed a state of things, the existence of which had not been suspected. Engineers were familiar with the smooth surfaces of steel plates nicely rolled, but it was found that some of those beautiful surfaces after being subjected to the process left the plate deeply pitted. He had seen pits ¼-inch deep where the oxide had been rolled in in lumps. Being harder than the steel, it had been forced in and remained unobserved and unsuspected. Another defect had also been brought to light by the practice of the Admiralty. Lamination was sometimes discovered in the plates, and in a ship now building it had been found to an extent sufficient to condemn one hundred large plates. Nothing of the kind could be suspected until the oxide was removed. The mischief originated from the rolling in of the oxide. The object of the Admiralty in removing the oxide was to prevent galvanic action

Mr. Farquharson.

Mr. Farquharson. upon the plate. But another result of this practice was that the steel, when entirely freed from the surface oxide, did not wear evenly. The plates experimented upon were 2 feet long by 1 foot wide, and the oxide was removed by filing in one series, and by pickling in another, so as to make sure that no element of uncertainty was introduced. After the plates had been immersed in salt water six months, some parts of the surface showed the filing-mark distinctly, while others had not been pitted, but were corroded less or more. The attention of the late Sir William Siemens had been called to the matter, and he said, "This is the manganese not evenly diffused." Whether that was so or not, the inference drawn by some engineers from the occurrence was that, considering the small percentages of carbon and manganese which constituted the material steel, the best results could hardly be expected unless the ingredients were evenly diffused. After some time the Admiralty anxiously considered what ready method was available to ascertain whether this was the case or not. Such a method had been found. He had discovered in some experiments that when mild steel was raised to, and kept at, a yellowish red heat, in contact with carbon, just as if it was to be case-hardened, the carbon would penetrate into the steel evenly if the composition was uniform, but not otherwise. The Admiralty had some hundreds of specimens, and the variety was very remarkable. A number of the specimens had been shown to the Ordnance Committee, and their variety was sufficiently marked to leave no doubt that a means of detecting the uniformity of the composition had been discovered. But as the testing, if specified, would be a matter of some importance as affecting the price of steel, the Admiralty had thought proper, before adopting it, to refer the matter to Messrs. Cammell and Co., who had made a number of tests, and had come to the conclusion that the proposed method of testing was unsound. The consequence was that the test had not been adopted; but he wished to mention some of the results. He had a report from the Company with regard to several specimens, p. 153, and it gave their tensile strength before being subjected to the process of case-hardening and afterwards, and the percentage of carbon. The test did not touch manganese. The percentage of carbon varied in the plates nearly 300 per cent., some being as low as 0·08, and others as high as 0·22. He certainly should not conclude from that that it was evidence against the test. In some cases, after the process, there was no stretch at all; indeed, he was certain that in all specimens of good steel that had come under his notice, where the process was applied, none of them would

TESTS of MILD STEEL MADE at the CYCLOPS WORKS, SHEFFIELD, in JANUARY 1883, by the CASE-HARDENING PROCESS PROPOSED by MR. FARQUHARSON, of THE ADMIRALTY, for SHOWING UNIFORMITY of the CONSTITUENTS of MILD STEEL. Mr. Farquharson.

Number of Sample.	By whom Manufactured.	Description of Steel.	Normal Condition before Case-hardening.			Result after Case-hardening.	
			Tensile Strength per Sq. Inch.	Elongation per cent.	Carbon per cent.	Tensile Strength per Sq. Inch.	Elongation per cent.
			Tons.			Tons.	
1	Cammell & Co.	Siemens-Martin	31·15	26·56	0·21	24·36	1·6
2	„	„	26·72	28·90	0·20	28·43	1·6
5	„	Bessemer . .	31·24	18·75	0·11	..	..
6	„	„	26·40	28·14	0·12	26·66	Nil
7	J. Brown & Co.	„	32·38	18·75	0·16	31·45	1·6
8	„	„	27·64	25·78	0·12	..	..
9	„	Siemens-Martin	27·89	25·00	0·15	..	..
12	Butterly Co. .	„	39·08	20·31	0·18	..	..
13	„	„	27·13	31·25	0·17	28·29	3·2
14	„	„	29·04	27·34	0·15	30·49	1·6
15	„	„	27·46	25·78	0·17	..	..
16	„	„	27·61	33·59	0·15	..	..
17	„	„	29·42	25·78	0·15	..	..
18	„	„	25·90	28·12	0·22	..	..
19	„	„	27·45	24·21	0·17	..	..
20	Bolton Co. .	Bessemer . .	29·33	25·78	0·10	..	..
21	„	„	30·50	19·53	0·09	..	..
22	„	„	30·86	21·87	0·11	..	..
23	„	„	31·87	24·21	0·09	28·35	1·6
24	„	Siemens-Martin	27·40	21·87	0·22	29·48	1·6
25	„	Bessemer . .	25·49	27·34	0·08	24·46	1·6
26	„	„	32·31	22·65	0·08	..	..
27	„	Siemens . .	27·36	25·78	0·21	..	..
28	„	„	26·95	29·68	0·17	..	..
29	„	„	26·32	30·50	0·15	..	..
30	Landore Co. .	Siemens-Martin	25·34	27·00	0·14	26·77	1·6
31	„	„	25·61	31·25	0·14	..	..
32	„	„	30·62	21·00	0·17	33·43	3·2
33	„	„	30·00	26·25	0·19	..	..
34	„	„	30·45	22·00	0·17	25·97	1·6
35	Steel Co. of Scotland .	„	31·10	20·30	0·18	26·57	1·6
36	„	„	30·90	25·70	0·18	..	..
37	„	„	31·10	27·30	0·17	26·61	Nil
38	„	„	26·20	27·30	0·18	26·53	1·6
39	„	„	26·60	25·00	0·19	24·15	1·6
40	„	„	27·00	30·80	0·17	32·23	3·2
41	Spencer, Newcastle.	„	25·70	23·43	0·10	..	..
42	„	„	24·99	20·31	0·10	24·52	1·6
43	„	„	24·83	23·43	0·10	..	..
44	„	„	26·88	22·65	0·10	..	..
45	„	„	23·54	31·25	0·10	..	..
46	„	„	25·84	29·68	0·10	..	..

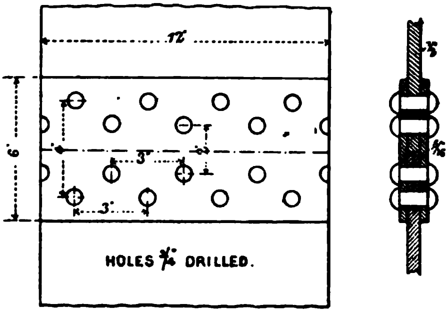
have any stretch. He challenged any one to produce a sample of

Mr. Farquharson. good steel, subjected to the process, that had any stretch at all; it would be as brittle as glass. In other cases there was a stretch of 3·2 per cent., and it was not uncommon to have 1·6 per cent.

Mr. Longridge. Mr. R. C. LONGRIDGE said that, with reference to the materials entering into the construction of steam-boilers, he could endorse the statement of Mr. Fletcher that iron was likely to go out of use. Steel was being employed not entirely but very freely, and the quality was very different from that used some years ago. The old sort of steel spoken of by Mr. Fletcher formerly gave a great deal of trouble. There were several cases of boilers bursting under the hydraulic test owing to the plates having to be thinned at the corners, and not being properly annealed afterwards. Since then engineers had a different material to deal with, and a boiler maker in Lancashire had told him that steel plates could now be treated very much as if they were iron, and they need scarcely trouble themselves about annealing; in fact, there need be no fear of punching the plates instead of drilling them. With reference to the joints or seams used in the construction of steam-boilers, the Author had given in the Appendix to the Paper nine cases of what he called the best types of riveted joints in use in modern practice. The first were Nos. 1 and 2, pp. 128, 129, and the tensile strength of the joints was stated, in percentage of that of solid plate as "deduced from experiments." The figures he believed were nearly accurate, but in the case of No. 2, he thought that the Author would have been more correct if he had given the percentage at 45. He objected, however, to obtaining the percentages in the seven following cases "by calculation." He would almost defy any one to calculate the percentage of strength of a riveted joint as compared with a solid plate. It was true that the Board of Trade gave a rule, $\frac{P-D}{P} \times 100$ = percentage of strength of plate at joint as compared with the solid plate; but he did not think that was correct. In another Paper issued by the Board of Trade, it was expressed in a different way, and more correctly. The percentage of strength in the case of No. 4, was given as 68. He had not actually tested joints of those dimensions; but he had had some experience with riveted joints, and he believed that 58 would be more nearly correct, and in the case of No. 5, he thought that 62 would be nearer than 72. The rule of the Board of Trade he thought was a little unfortunate. Taking the percentage by that rule a factor of safety was obtained of 5 or something more. However, there were several cases of which he knew, where the factor of safety was only 4, as ascertained by actual experiment.

It was a pity, therefore, to speak of the strength of riveted joints by calculation; at any rate, the results should not be put into the same Table with others that had been deduced from experiments. If the first two examples had been calculated in the same way as the rest, instead of working out to 43 and 40 respectively, he thought they would probably both be found to be about 55 or 60. The Author had made no reference to the arrangement of holes for double riveting known as "chain" riveting, where the holes of the second row were immediately behind those of the first row, instead of being arranged "zigzag," as shown in the examples of double riveting given in the Appendix, p. 129. That "chain" riveting was stronger than "zigzag" riveting had been clearly proved in the course of a number of experiments made by Mr. Kirkaldy for the Boiler Insurance and Steam Power Co., and as the Mr. Longridge.

FIG. 25.



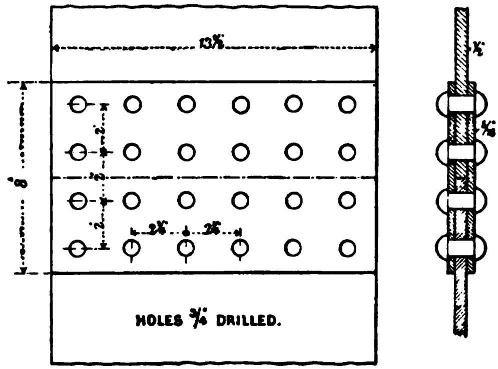
Scale ¼.

results of those experiments had never been published, the particulars of some of them might be of interest. Two butt-joints made with ½-inch plates, with drilled holes arranged as shown in Fig. 25, and two butt-joints made with plates of the same thickness, but with holes drilled as shown in Fig. 26, had all been tested to destruction with the results given below; the holes were all accurately drilled to ¾-inch diameter, the strips in each case were

—	Tensile Strength of Solid Plate.	Total Ultimate Stress borne by the Joints.	Ratio of Strength of Joint to that of Solid Plate.
	Tons per Sq. Inch.	Tons.	Per cent.
Means for two joints, Fig. 25	22·45	85·20	63·35
Do. do. Fig. 26	22·80	102·25	66·20

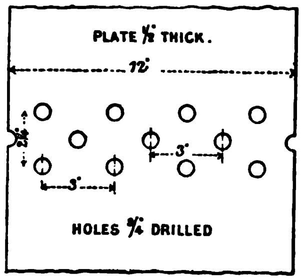
Mr. Longridge. $\frac{5}{16}$-inch thick. The chain-riveted joint was thus shown to be the stronger, and as it was also better for calking purposes, owing to the rivets being closer pitched, several boiler-making firms that he knew of had entirely discarded the zigzag arrangement for double riveting. He might also mention that some plates which had been perforated with holes arranged for "chain" and "zigzag" riveting

Fig. 26.



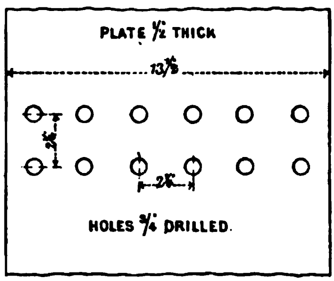
Scale ⅛.

Fig. 27.



Scale ⅛.

Fig. 28.



Scale ⅛.

respectively, gave similar results as under; the plates were all ½-inch thick, and the holes were accurately drilled ¾-inch in

——	Tensile Strength of Solid Plate.	Total Ultimate Stress borne by Perforated Plates.	Ratio of Strength of Perforated Plate to that of Solid Plate.
	Tons per Sq. Inch.	Tons.	Per cent.
Means of two tests, Fig. 27	21·7	12·20	56·4
Do. do. Fig. 28	20·9	13·45	64·4

diameter. It would be observed that the number of holes and the net sectional area through any of the rows of holes were the same in both arrangements. It should be noted that the ratios in these cases had not been merely "calculated," but were from the actual facts, as obtained from Mr. Kirkaldy's machine. Mr. Longridge.

As to the strengthening of internal flues, of the many examples exhibited the one he preferred was Fig. 4, the bridge-section hoop. He did not, however, say that other modes were not as good. The flanged seam was excellent; but his objection to it was that as nothing could prevent men from being careless, collapses from shortness of water could not always be avoided, and the difficulty of repair was very great; nothing could be done without taking the end plate off. In the case of the bridge-section hoop, the repairs could be effected without taking the end plate off; the rivets could be knocked out, and stretching hooks got in, so as to draw the plate together, and pull it out at the front end; that was frequently accomplished in the case of a collapsed furnace. It could not be done with the flanged seam, nor with such a seam as had been mentioned by Mr. Paxman. The majority of the flanged seams were made with a sharp bend. The metal was much punished by flanging in that way, and there was frequently trouble from grooving at the root of the flange. He had never come across the method shown in Fig. 8; but in old boilers the flues were frequently secured place by a plate, which was either riveted or left loose round the flues. That sort of arrangement never answered, and he did not think there was much use in that shown in Fig. 8. He believed that expansion-hoops were not made at the present time. They had been found so unsatisfactory that the makers gave up constructing them for that purpose, but made them so that they would not allow for expansion, and then they served as strengthening hoops well enough. They were now manufactured like Fig. 4, as bridge-section hoops, but so long as they were thin to allow for expansion and contraction, they were troublesome. With reference to the special types of boilers, he was sorry the Rastrick type had been mentioned. He believed Mr. Marten would bear him out that the sooner that type became obsolete the better. One point ought to be particularly attended to in designing boilers, namely, to allow for expansion. Plans were sometimes submitted which were utterly and hopelessly impracticable, no allowance being made for expansion. It was impossible to prevent expansion, and therefore it was absolutely necessary to make allowance for it. It was also most important to afford every possible facility for examination

Mr. Longridge. and for repairs, and in arranging for this the question of the seating had to be considered almost as much as the actual design of the structure.

Mr. Cowper. Mr. E. A. Cowper felt it incumbent upon him to say a few words on boilers, as from lack of time he had been obliged to omit the subject altogether in his lecture on the steam-engine which he had delivered last Session, as one of the course on Heat in its Mechanical Applications. His opinions had been formed after long practical experience. His first drawing, when he entered the drawing office as a lad, had been of a boiler. At that time he could not obtain satisfactory rules for the power, the strength, the steam nor water-space, staying, &c., &c.; but he had ever since striven to ascertain practically what a good boiler should be, or might be, to suit special cases. For instance, there was no absolute necessity for making a boiler of a certain length, if the space available would not allow of it; a shorter boiler might be so proportioned, and properly set, as to work perfectly well in the shorter space. He would endeavour to follow the Author of the Paper in his division of the subject. In the first division, "The Materials Used in the Construction of Steam-Boilers," the Author spoke of the names given to iron plates by different makers being very misleading, but Mr. Cowper having himself used plates from nearly all the best English makers, found each man reliable if he insisted upon the maker's signature on every plate; the maker then considered his credit at stake for supplying the particular quality stamped on the plate, were it "Best" or "Best Best." Some unprincipled makers of plates, however, would put on any marks, or any number of "Best Best's," as they were ordered by their customers, but they would not put their name to them; they seemed to look upon the order as for a plate with a pattern on it, consequently it was no wonder that a customer got a "ship-plate" or a "boat-plate." This was a reproach to the iron manufacture of this country. He agreed with the Author, that boilers were to be found made of iron that was "neither suited nor intended for boiler-construction," and he knew that boilers were sometimes ordered without so much as an attempt to specify, or ascertain that proper plates were used. All the "Best Yorkshire Plates" made with the "Better Bed Coal" (which was free from sulphur) were excellent, but expensive; they were good for crown plates over the fire. He had seen a Cornish boiler in which the top of the flue of "Best Yorkshire Iron" had come right down from shortness of water, and yet the plates were not cracked nor broken, but continued to hold the water and steam. It was the rarest thing

to see a bad "Best Yorkshire Plate," for a reason which he wished every maker of plates would follow, namely, that immediately a faulty plate was found by any customer or boiler-maker, the maker had it back and supplied another good one in its place, and as every plate had the maker's name on it, there was no difficulty in so doing. Some plates made from iron-stone containing manganese were very good, and even single "Best" plates would flange well. He might mention that if the flues of a Cornish or Lancashire boiler were flanged with the Adamson joint, it was an approximate safeguard against common or bad plates being used, and some inferior boiler-makers objected to flanged joints for this reason. There were several good brands of Staffordshire plates, but not so many as could be wished. Mild steel was undoubtedly far superior to iron for boilers, and was so ductile that, as had been stated, a small boiler 4 feet in diameter with the metal only ¼-inch thick, made at his request by Mr. J. T. Smith, M. Inst. C.E., of Barrow, stood a pressure of 420 lbs. per square inch, and only wept at strained joints; it was then well calked, and stood 350 lbs. per square inch, but could not be burst or ripped open by all the pump power put on. This experiment was made at a most opportune moment, as the "Livadia" plates gave way just after the little boiler was made, and before it had been proved. He did not hold with the usual method of considering the strength of a boiler, although perhaps the final result was not very different, except that he advocated rather stronger boilers. His argument was, that if a boiler at the time of proof, or at any other time when it had worn thinner, was strained beyond the elastic limit, it was not the same boiler; it was more or less out of shape, and probably would leak, and have unfair strains on some of the plates or rivets. He therefore always took care that the strains should be well within the elastic limit when proving at twice the working pressure, and always made the trial with water at 210° or thereabout, as he had found by experiment that a boiler was more severely tried by water at that temperature than by cold water. Mr. Cowper.

The second head of the Paper, "Joints or Seams used in the Construction of Steam-Boilers," extended over such an extremely wide field, that he would confine any remarks more particularly to those forms that had already been touched on. The "Upright," or "Rastrick boiler," was not a desirable form, except that it occupied little room, and could therefore be placed near the furnaces; nor was it very safe, partly because it was so often ill-treated. It was frequently forced too much, as it was generally in the middle of a mill, where millmen and puddlers wanted

Mr. Cowper. power, and it sometimes was not completely under the sole control of the boiler-man or stoker, since it did not require stoking, but was worked with the waste heat from the puddling or ball furnaces. If the heat was directed so as to impinge upon the plates, they would give way sooner or later; though if the boiler was protected at that part by brickwork, and the current of the products of combustion attained a circumferential motion, they might be allowed to sweep round the boiler. But the heat from four puddling furnaces acting on one boiler was very searching, and the water must be good if the boiler was to stand it long without repairs.

Another far too common form of plain boiler resembled a very long sausage, sometimes 60 feet or even 80 feet long, fired below perhaps with the waste gases from the top of the blast furnaces at ironworks. The top was often exposed to the weather, and the result was that all the lower part of such a boiler was hotter, and longer than the top, and the extremities turned up somewhat, and then the boiler might bear with its whole weight on the centre. To cure this, two bridges were now generally placed over such a boiler, at about one quarter of the length from each end, and the boiler was suspended from these bridges; sometimes more bridges were added, and the boiler was hung on spiral springs so as to be partly supported, although it bent up when hot, and became straight when cold.

All boilers to carry pressure ought to be cylindrical if possible. In a locomotive boiler this was not altogether possible with the fire-box, but locomotives with oval barrels had blown up. The shell and furnaces of a marine boiler could be made cylindrical; and of late years, since a considerable pressure had been carried, they were almost always so constructed with well-stayed ends; the uptake was the weakest place and had to be stayed like the flat sides of a locomotive fire-box. It was just as important to have the flues of boilers cylindrical as the shells, and he entirely disapproved of oval flues, or flattened flues, whether stayed here and there, by vertical tubes connecting the top and the bottom, or not. The two flues through a Lancashire boiler formed admirable supports to the end-plates, besides reducing considerably the area subjected to pressure, as compared with a single-flued or Cornish boiler. An excellent plan for preventing straining and grooving in the barrels and angle-irons of locomotive boilers, was that followed by Mr. W. Stroudley, M. Inst. C.E., namely, applying two angle-irons, one inside and the other outside the barrel, and facing them and riveting them to a planed tube-plate with rivets in drilled holes. He considered domes decidedly useful, though they were a source of

weakness if not applied with judgment, and for this reason:—the part of the shell under the dome, which should never be cut out, was not kept to the true curve of the shell by any pressure from the inside, as it was subjected to equal pressure on the outside and inside, and therefore being in equilibrium and curved, it did not take the circumferential strain. But if a wide horizontal plate-stay were securely riveted to the shell across and under the dome, the boiler would be as strong as though it had no dome. No doubt boilers had given way for want of this obvious precaution. Great care ought to be taken, not to attempt to force in, with an excess of pressure, rivets that were too long for their position. He had seen several boilers, riveted by one of the first machines, which had a definite motion, and no yielding part or limit of pressure, in which the plates were cracked in many places from hole to hole, and from holes to the edge of the plate, and it was fortunate they had not blown up under the 50 lbs. pressure per square inch to which they were subjected. Mr. Cowper.

With regard to the third division of the subject, namely, the "Staying of Steam-Boilers, and the Strengthening of Internal Flues," he would refer to the experiments instituted by the late Sir William Fairbairn, which, he believed, were carried out by Professor Unwin, and described in a Paper read before the Royal Society.[1] These showed that the flues being, so to speak, in a state of unstable equilibrium, and not very stiff in themselves, were exceedingly weak if long, as their strength depended much upon their being retained in a truly cylindrical form, by being fixed to the ends of a boiler. In 1843 he had seen some very badly-proportioned Cornish boilers, with the flue about 5 feet in diameter, and the shell about 6 feet 3 inches in diameter. He pointed out their great weakness owing to the size of the flue at the time, and about six months after one or more of them gave way, the flue coming right down. In 1845 he arranged some angle-iron rings at intervals round the flues of some boilers, of course putting some short distance-pieces, or thick washers, between the angle-irons and the flues. At the time he had some misgivings as to the deposit being properly cleaned out from between the rings and the flue, and he afterwards put flat rings edgeways, with the edge touching the flue only $\frac{1}{8}$-inch wide, so as not to keep the water from the flue, the rings being only fitted to the flue in pieces riveted together, and not in any way fixed to

[1] Philosophical Transactions of the Royal Society of London. For the year 1858, p. 389.

Mr. Cowper. the flue. This answered perfectly, but on the introduction of the Bowling expansion-rings, he adopted them as a great improvement, since they prevented the flue from being quite so rigid from end to end. When they expanded more than the shell of the boiler, as they did from the greater heat, the front and back plates did not suffer from bulging out and leaking, like scores of Lancashire boilers, at those parts of the front plate where the flues and shell were near each other. After this, however, the Adamson joints came into use, in which each plate of the flue was bent round and welded, and then the ends flanged up, the rivets through such flanges being entirely in the water, so that no rivet was exposed directly to the fire. This alone was a gain; but the way in which the flanges kept the flue in shape, at short intervals, was most admirable, and an incidental advantage was that bad plates could not be worked in this manner. Lastly, the benefit of a little elasticity was obtained in the direction of the length. As a matter of detail, not always attended to, a flat ring should be riveted in between the flanges for the facility of calking. This added to the strength materially, and if it were wished to make a very strong flue, it was only necessary to have each ring of plate rather short. The flange ought to be turned up with an easy curve, because the body of the flue exposed to the fire tended at all times when the boiler was in use to be hotter than the flanges, which were exposed to the water and not to the fire. Fox's corrugated flues gave very great strength when exposed to external pressure; but he could not say whether the effect of the ridges which caught the fire most, made up, or more than made up, for the depressions which undoubtedly caught the fire least; they were of course extremely elastic endways.

An admirable invention of Mr. Galloway was that of heating and circulating-tubes, now commonly called "Galloway Tubes." Being larger at the upper end than at the lower end, they were easily introduced into the flues of a Cornish or Lancashire boiler; the flange of the lower end passed through the hole in the upper side of a flue, whilst the flange of the upper end rested on the top of the flue. These tubes gave a considerable increase of surface to such boilers, and did not burn out if kept some distance from the bridge, as they were freely supplied with water from below, owing to the quick circulation set up, whilst there was room for steam and water to escape readily from their large upper ends. He considered them best placed alternately, and slightly diagonally, in the flue of a Cornish or Lancashire boiler, where they did

not interfere with the cylindrical form of the flue. The flame and products of combustion ought never to be nipped at the bridge, as such a course was very likely to ruin the crown-plate; but the flame should be allowed to develop freely, as there was none too much height for the ash-pit, bars, fire and flame in a cylindrical flue, and it was dangerous to make the flue oval for the purpose of getting more height. He objected to long heavy bolts, extending through the boiler from end to end, for staying the ends of a Lancashire boiler, as they were extremely rigid, and were the last parts of a boiler to get hot. They did not become heated until long after the flues and shell had been exposed to the fire; he much preferred well-arranged gusset-stays and strong angle-irons across the plates inside the boiler. Mr. Cowper.

Fourthly, as to "General Remarks on the Construction of Steam-boilers," he would by all means prevent stratification of the water, by which he meant allowing the bottom of the boiler to remain cool whilst the upper part was heated; and here any theoretical ideas about the water being put in at the bottom cold, and being gradually heated as it rose to the surface to form steam, must be put aside in deference to more practical considerations. If the bottom of a boiler was cool, and the top hot, most improper strains were brought into play, as the bottom of the boiler was then shorter than the upper part; and if the boiler was a long one, very probably leakage would be set up, as well as the plates be strained severely. In heating a cold boiler, steam should be blown into it if possible to the bottom from another boiler; but if there was no other boiler from which steam could be got, then a fire basket should be introduced through the lowest soot-hole door to warm the bottom of the boiler. The feed-water should never be introduced at the bottom, but through a long horizontal pipe a little below the water-line and above the crown of the flues, lest the feed-pump valves should leak, and lower the water too much. This plan he believed had been introduced by Mr. L. E. Fletcher, and it was a very good one. He himself generally used a copper pipe about 5 feet long, with the end open, but with slits all along, formed by two small cuts and one cross cut, and bending the tongue of copper inwards, thus coaxing the water out of the pipe throughout its whole length. He had known cases where the end of the pipe had been made closed, with only small round holes, and the water being bad and stopping the holes, the pipe became choked, and the force-pump tore off the copper pipe from its union nut. If from any cause, such as a limit of weight of boiler, or from there not being room to get a long boiler into its place, it

Mr. Cowper. became necessary to make a boiler in several lengths, it was very important to have, as nearly as possible, equal lengths of steam-pipe of large size, from each section to the dome, so that there should not be any material difference in the pressure in any one section; for it should be remembered that 1 lb. difference of pressure per square inch would make 2 feet difference in the level of the water, which was enough to bare any flues; and there should be two large water-pipe connections between all the sections, so that the water might circulate freely and be all at the same temperature and at the same level. Compound boilers thus arranged worked perfectly well, and he had nine such in operation at the present time. He had given particulars of a long series of experiments with one, in his lecture on the steam-engine. With a compound boiler a large area of water-surface was obtained, and the water would not get so low in a short time as if it had less area on plan.

Boilers with very little water in them could sometimes have the steam raised in a very short time, as in fire-engines, which, however, generally had the boiler kept warm by a few gas jets. But boilers that had very little water in them were very unsteady in their supply of steam. If the steam could be got up quickly it might go down quickly, unless closely watched; therefore stationary boilers with a good quantity of water in them were the most satisfactory for ordinary purposes. He had designed and worked a boiler regularly at 220 lbs. per square inch, and the performance of such boilers was as quiet as of any low-pressure boilers. He had experimented with a very small boiler, consisting of a coil, at 1,200 lbs. pressure per square inch for hours together, and produced the result aimed at, namely, the quick conversion of neutral fat into acid fat and glycerine on Tilghman's plan.

All circumstances had to be taken into account in designing a good boiler, and there were many that affected its thorough efficiency and power of working economically at different rates. It was not sufficient to give ample heating-surface; there might be too much, and he knew of a case where steam could not be raised in a boiler simply from there being too large a surface in numerous small tubes, so cooling down the products of combustion and causing friction, that there was no draught in the chimney. There must be area enough through the tubes or flues to allow the products of combustion to pass freely, so as to maintain the fire properly. This was sometimes neglected by too much contraction at the bridge, and sometimes at the ash-pit. He had

known a Cornish boiler on the point of being exploded from a single rivet not having been fastened, and being blown out; the boiler lost water quickly, and the top of the flue was nearly brought down. Mr. Cowper.

The necessary fittings to a boiler were nearly as important as the boiler itself. In his opinion there should be the following fittings to every stationary boiler, all the principal ones having wrought-iron necks riveted to the boiler, and with faced flanges to receive the fittings.—There should be three modes of ascertaining the level of the water, namely, three gauge-cocks, glass gauge and float stone, two safety-valves, pressure-gauge, feed-pump and check-valve, feed-valve and relief-valve, injector, blow-off cock, scum-cock (for there was sometimes as much dirt on the top of the water as at the bottom), vacuum-valve (to prevent the boiler filling with water when the steam went down), man-hole at top and man-hole or mud-hole at bottom, steam-valve, damper, means of regulating the quantity of air admitted over the fire to prevent the formation of smoke, and soot-hole doors to give every opportunity for cleansing the boiler and flues. If there was much carbonate of lime in the water some astringent substance should be added to it, when the lime would be precipitated in an amorphous state, and could be blown or swept out; or the water should be heated first and then filtered. Several excellent mechanical stokers had been introduced, amongst them Vicars's stoker answered very well, and enabled small coal to be used in London at one-half the price of large coal, so that with a good engine 1 HP. per hour could be produced for $\frac{1}{8}d.$

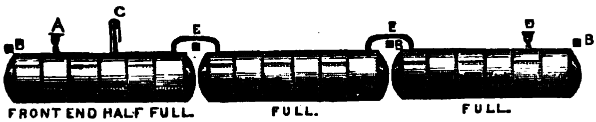
He would only add one remark; if a horse was badly bred, badly fed, worse groomed and over-driven, he would turn out a failure; but a boiler badly designed, of bad plates, badly put together, occasionally kept short of water and over-driven, would sometimes kill half a dozen persons, and perhaps the man who treated it badly, though the effects seldom reached the maker who had brought it into existence. He believed that fewer bad boilers would be produced if the makers always lived over them. On the other hand, he might say from long experience that a boiler properly designed, of good plates, well put together, thoroughly proved, and then well treated, never was blown up, and would not need repairs for many years. There was, in fact, no more satisfactory instrument than a good boiler.

Mr. E. B. Marten remarked that when many years ago he was welcomed to the Institution by Mr. Robert Stephenson, the first words he heard from him were that Engineers learned most from Mr. Marten.

Mr. Marten. failures. It had been his lot to study almost all the failures of boilers, and to ascertain the particulars of each, and he had models of most of the leading explosions that had taken place, one of the earliest boxes of models being prepared for a President's conversazione in 1871, and another in 1872. He had arranged the causes of failure, in the way suggested by the Parliamentary Committee of 1869–71, under the three heads of faults of construction, faults that could be only seen by inspection, and faults of management; in other words, faults of makers, of inspectors, and of attendants. Out of four hundred and forty-five explosions during the last ten years, one hundred and fifteen were put down to faults of construction. His investigations had lain chiefly among boilers of the hardest worked kind in ironworks, and he wished to make a few remarks as to the failures he had observed and the evils to be avoided. He had met with steel plates, and, like many others, had noticed the great uncertainty of the material. He was glad to find that as the manufacturers understood their work better, that difficulty was being got over. A special difficulty was where steel plates had been introduced for repairs, owing to their tearing out from the wrought iron with which they were connected. Allusion had been made to the brands of "Best, Best," &c., and the want of the maker's name. During the last few weeks he had met with specimens where the owners had been disappointed, thinking that they had got the very best make of iron, and had only "single Best," the commonest brand known. Allusion had been made to cover-plates for joints. He had sometimes met with them even when the cover-plate was exposed to the fire. A notable instance had occurred in which an explosion had been caused by the burning of the outside cover-plate, and notwithstanding remonstrance, another was worked like it, and burst in a fortnight. Cover-plates of merchant-bar were used in making the early Rastrick boilers of large diameter, but, although lasting a long time, they eventually were burnt through. A great deal had been said about weak tubes. From the records he had collected, he had found that the tubes which failed had about half the strength computed by the usual mode of calculation; so that in practice it appeared that the tubes were only safe at half the pressure usually permitted. It was said in the Paper that strengthening hoops might be put on eccentrically, but he had found that lead to mischief, especially where the boilers were gas-fired and the bottom became nearly as hot as the top of the tube. He had not had much experience with corrugated plates, but he had not noticed that the front-plate had been caused to

bulge particularly, and he should like to ask if the corrugation increased with the pressure, and therefore tended to shorten the tube, and to partly restore it as a stay. Reference had been made to the unsuitableness of some parts of a boiler. He had met with a man-hole in a vessel intended to bear 450 lbs. pressure per square inch, and the calculated strength of it was the same as for a boiler for about 50 lbs. It was only a common cast-iron frame for a boiler intended for that pressure. In regard to the different classes of boilers, one of the greatest difficulties he had met with had arisen from bad imitations of some well-known boilers. Good makers had learned to allow for expansion and contraction, and others had attempted to make the same class of boiler without such experience, and had, perhaps, put a cambered rigid end so as to prevent expansion of the tubes entirely. Externally fired, plain cylindrical boilers had no doubt done good work, but they were unsuitable for very high pressure or rapid work. Some instances had lately been met with where the Mr. Marten.

FIG. 29.



Scale $\frac{1}{240}$.

A Steam valve. B B B B Bearers. C Float. D Feed valve. E E Connecting pipes, bent to allow for expansion.

pressure had been excessive, and the boilers had been made to do twice the work intended. The plain cylindrical boiler was easily overworked. Seam-ripping had been one of the greatest troubles he had encountered in all his experience. Where it occurred he had had the plates tested, and had satisfied himself that it was owing to the want of ductility. Had the boilers been made of such tough mild steel plates as he had seen tried at Barrow, where 450 lbs. pressure per square inch was put upon a 4-feet boiler, they could not have possibly burst or ripped. The only result of the experiment was to elongate the rivet-holes until the boiler leaked so badly that it could no longer be used. He had known boilers as long as 104 feet, and sometimes quite turned round in a circle. It had been stated that the best way to divide a boiler was with two connections. He had always recommended that it should be divided with only one connection, as shown in Fig. 29. The feed-water advanced from one to the other, and then on to the last, and there was the advantage

Mr. Marten. that the water flowed one way and gradually became hot, and the fire went the other way, as he had previously explained to the Institution.[1] With regard to the Rastrick boiler, ironmasters had been much blamed for allowing so much heat to escape into the air, and efforts had been made to economize it. A vast amount of work had been done by the Rastrick boiler, and he always spoke of it as a good old servant, made by a fellow-townsman of his. The only difficulty was that it must stand amongst the workmen, but that applied also to all other furnace-boilers. Perhaps no boilers had killed more persons, except marine boilers, which had caused the sinking of the vessels. He did not suppose that any were now being made. Allusion had been made to one case, in which an ironmaster was disappointed because he took out a boiler 10 feet in diameter, working at 70 lbs. pressure per square inch, which was only as thick as a shilling, and he put in another 9 feet in diameter, working at a pressure of 50 lbs., and in a few years it burst; the reason being that the iron was so very poor and brittle that it would hardly bear falling from an upper story to the ground without breaking to pieces. The difficulty he had met with in chimney boilers was that they were so narrow that it was difficult to inspect them, and the fittings being so much above the floor-level they were often neglected, especially in the night turns. One curiosity about boiler-explosions was that they seemed to come like epidemics. During the last few years the little boilers, formerly called crane-boilers, appeared to be giving way. As to these little upright boilers, it had often been said that the cross-tubes added nothing to their strength. He was not of that opinion, and he should be glad to know if any member could give information as to experiments upon the subject. He would only add that every new material, form, or design would no doubt lead to a new set of faults which would have to be carefully watched.

Mr. Fox. Mr. Samson Fox said that the Author had referred to various kinds of flues as having an important part to play in the boiler as stays, and he had given timely warning in regard to the corrugated flue. As Mr. Fox had made a large number of experiments, both on the question of its resistance to collapse, and its assistance to the boiler as a stay, he might be permitted to give a short account of it. He had tested for collapse with cold water a large number of welded tubes made of steel of various tensile strengths, some of them had been plain 7-feet lengths without any joint in the centre, and others had the Adamson joint, also a large number

[1] Minutes of Proceedings Inst. C.E. Vol. liv., p. 164, Fig. 3.

of corrugated flues. He had undertaken the experiments in connection with the Board of Trade and Lloyd's, with a view to finding what resistance a plain tube offered to collapse, because up to that time no data existed but those supplied by Sir William Fairbairn, which had been based on experiments made on small models of very slight section. Mr. Fox constructed an apparatus in which a man could sit within the tube being experimented on. He first drew lines through the tube at four points vertically and horizontally. Crossing these lines by drawing circumferential rings 6 inches apart, he gauged it accurately at these points of intersection, to $\frac{1}{100}$ inch, to ascertain whether the tube before starting was a true circle or not. Water-pressure was applied in increments of 50 lbs. per square inch, and the pressure relieved from time to time to see if any starting of the tube had taken place. Generally, in a plain tube made from a $\frac{7}{16}$-inch plate, 3 feet 2 inches in diameter and 7 feet 4 inches long, it was found that a shivering took place, which threw off the scale of the plate at about 200 lbs. pressure to the square inch. In a plain flue, at 225 lbs., or say up to 240 lbs. per square inch, a small bulge not more than 4 inches long by 4½ inches wide, would be set up. It was something like a lemon cut in two with the convex side projecting; and this occurred at any point in its surface, but a very little additional pressure caused it to spread to the whole length of the tube as far as it was exposed to pressure. In dealing with the Adamson jointed flue he considered that collapse should take place about the centre between the points of support, say between the central rib and the end of the flue; but in a number of experiments it was found to take place at any point, and not equidistant from the two supports. In all cases, like the plain flue a small bulge was set up, and on testing and cutting through it, the material was invariably found slightly less tenacious than the rest of the plate. The pressure seemed to attack the weakest spot in the plate, no matter where the support was, and then of course the bulge afterwards spread. It followed that if it was wanted to support a flue properly, the points of support must be placed near together, so that it almost came to the same thing as having them about 6 inches apart, because some of the bulges had started quite close to the flange-seam. Of course if it were necessary to support a flue, so as to make it proof against collapse, at intervals of 6 inches apart, the question was how far the corrugating of a plate was right for the purpose of thorough support. He thought that fairly explained collapse under the cold test. With reference to the testing of boilers, Mr. Fox.

Mr. Fox. to ascertain how far the flue was a support to the ends as a stay, he generally found that the Adamson joint allowed the end of the boiler to expand a little more than the corrugated flue. The corrugated flue might yield $\frac{1}{4}$ inch when the Adamson joint would give about $\frac{3}{8}$ inch. That was quite natural, because the Adamson joint was a series of angle-brackets fastened together with lines of rivets, and the point of pull was not in a line with the line of rivets, consequently the angle-brackets opened a little at the joint. The corrugated flue was a series of rings of two different diameters, and if it was required to be lengthened it was necessary to expand the smaller ring and contract the larger. That was the place where the corrugated flue was certainly very strong in tension, while it was correspondingly weak in compression. It would shut up easily at the end, because there would be no distortion of the metal; but in pulling it out it was necessary to expand and contract the different diameters. The Author had stated that it would be well to surround a corrugated flue with a series of stays to protect it in the case of low water and its becoming red hot. A large number of those flues were at work; in land boilers alone there were about one thousand, fitted with six thousand lengths of corrugated flues, and there was also a large number in marine boilers, with at least ten thousand lengths of corrugated flues. In a few cases the water in the boiler had got too low, and in every such case the heat first of all impinged on a certain portion of the flue, and as there was no water to cover it the plate softened. But on either side of that point there were two ribs in the shape of the next two corrugations, either longitudinally or circumferentially, and these had always so far protected it that, in cases of collapse, the failure had not been total, but a simple pocketing, so to speak, of the material from the pressure of steam on it while the plate was very hot. There was an instance of a boiler going across the Atlantic with a pressure of 130 lbs. of steam per square inch on a pocket in a corrugated flue 12 inches deep, no trouble having taken place in connection with it, simply because it was like a pot worked out by the pressure of the steam, with no corrugation whatever, and supported all round by the ribs of the remaining corrugations. It was not so with the plain flue. Wherever a plain flue had first lost its shape by collapse the failure was complete. In another instance, the case of a boiler fitted with a corrugated flue working at a pressure of 150 lbs. per square inch, the men in charge had allowed the water to go down, and being afraid to let their employers know, ran the boiler for a fortnight with a bulge in its furnace

without saying anything. In this case the two end corrugations were perfectly intact, and no supporting stays were required. In another case the pocketing had been even more severe in a ship 300 miles from New York, which went to New York and came back to England. There was no question that the corrugated flue supported itself inch by inch, both under cold-water pressure and when red hot as long as any corrugation was left in the plate, and without the least danger of fracturing or letting out steam or water. The fact that, between the English makers at Leeds and the German makers at Essen, more than sixteen thousand corrugated flues had been made and fitted into land and marine boilers within the last five years, decided the question as to the fitness, on every point, of the corrugated flue for the purpose for which it had been designed and manufactured. Mr. Fox.

Mr. D. S. Smart, in reply upon the discussion, said in regard to the fire-box shown in Fig. 10, that he had given it a taper towards the top of 2 inches, but not more, as a further reduction in the size of the furnace-crown would, by diminishing the best part of the heating surface, seriously impair the efficiency of the boiler. Priming might be prevented by allowing a large steam space, and, if necessary, by the addition of a perforated steam-collecting pipe fixed round the crown. He had been asked to explain how the cross-tubes in the fire-box were fastened, and in what way it was done. They were in this instance welded in, to obviate as far as possible double thicknesses of plates exposed to the heat, and this was a common method of fixing such tubes. The fire-box, which should be of a single plate when practicable, after the holes for the cross-tubes had been cut out, was rolled, and the vertical seam welded up. The cross-tubes were allowed to project about ½ inch at each end. The ends of the tubes and the plates surrounding them were then successively welded together over a smith's fire. Fire-boxes and flues of steel, as well as of iron, were treated in this way, and with the mild weldable steels now manufactured, seemed trustworthy. It had been remarked with reference to the fire-boxes of boilers of this type, that the cross-tubes did not add so much strength to resist collapse as might have been expected. It was first pointed out by Professor Unwin, that the length of a flue, other things remaining the same, determined approximately the number of segments into which it would collapse.[1] A long flue would merely flatten, while shorter ones would take, in section, what might be called the star form, Mr. Smart.

[1] Minutes of Proceedings Inst. C.E., vol. xlvi., p. 233.

Mr. Smart. the number of rays or segments increasing as the flues were shortened. Keeping this in view, it would be seen that a few cross-tubes would impart great additional strength to a long flue, but that a short flue would not be proportionately strengthened, as the segments into which it would naturally fall during collapse might fit more or less accurately between the tubes. It might be added that the fireboxes of vertical boilers, such as that shown, could be strengthened to withstand very great pressure by the insertion of screw-stays, attaching them to the outer shell after the method employed in staying locomotive fireboxes. It had been mentioned that the heating of steel plates at the corners to thin them down for the joints was objectionable. This difficulty was overcome by planing the corners, which was better than thinning on the anvil.

The importance of testing boiler-plates had been referred to, and Mr. Fletcher had given a number of instances of the plates of exploded boilers having proved almost devoid of ductility. As stated in the Paper this might be the result of long and severe service, and could not always be taken as proof of an original want of ductility. Even the best Yorkshire iron after long service was found to be extremely deficient in this respect. Another cause of the loss of ductility in boiler plates which ought to be mentioned, was the high temperature to which they were sometimes raised. This might be brought about either by an accumulation of deposit on the water side, or by their exposure to hot gases above the water-level. When heated to from 400° to 600° Fahrenheit, plates of B. B. boiler or Bowling iron might lose from one-quarter to one-half of their ductility. At a temperature of 400° Fahrenheit mild steel produced both by the Bessemer and Siemens processes might lose one-third of its ductility. Beyond this limit there was a still further decrease, but it had not yet been clearly defined.[1] The crown plates of the boilers which exploded at Blackburn in 1874, referred to by Mr. Fletcher, were exposed to the heat of the external flues, which was probably in excess of the limits named. The low ductility of the plates pointed out by Mr. Fletcher, the further reduction of ductility due to overheating, and the strains from unequal expansion, intensified in this instance by such overheating, went far to explain the cause of the explosion. The low ductility of the plates of these boilers could not have been the result of long service, as the boilers were nearly new, having only been at work

[1] Experiments by the Admiralty. "The Engineer," 31st March, 1882.

ten months. In view of the facts just mentioned, the highly objectionable practice of setting boilers with any parts exposed to the heat above the water-level could hardly be too severely censured. Mr. Smart.

With reference to equalizing as far as possible the expansion of the different parts of a boiler, both on raising steam and while at work, discussed by Mr. Cowper, it might be stated that the arrangement of the external flues of Cornish, Lancashire, and kindred types of boilers now adopted, accomplished this object to some extent. It was simply that the hot gases from the furnaces, after passing through the internal flues, returned first along the bottom of the boiler to the front, and thence passed away by the side flues to the chimney. Some years ago the common practice was to conduct the gases from the internal flues first into the side flues, leaving only the last of the heat to be taken up by the bottom of the boiler.

It was seldom thought necessary to test iron plates from first-class makers, and none but trustworthy brands should be used for boilers; but when tests were required they were generally only bending-tests, and the angles to which the strips were bent were arranged so that the amount of elongation of the outside of the curves was proportionate to the ductility expected. With regard to steel plates, up to the present time, when boilers were constructed under the supervision of the Board of Trade, Lloyd's Register, and some of the other leading inspecting companies, strips from every plate were tested; but many boilers were otherwise constructed, of which the steel was subjected to no tests, except those which might have been undertaken by the makers. The tests varied somewhat, but usually conformed pretty closely to those prescribed by the Admiralty, the Board of Trade, or Lloyd's Register. With regard to the temperature from which steel plates were cooled in the temper tests, the Admiralty specified a "low cherry-red" heat, and this expression, or "cherry-red," was generally adopted. Most people appeared to understand that a low cherry-red was that which was just merging into blue. This, however, was just about the point at which, when quenched, even tool-steel could not be tempered, but would, on the contrary, become somewhat softened. The Author practised this method of annealing tool-steel years ago. He was not aware that any satisfactory explanation of this phenomenon had been given; but it was referred to in Mr. Jeans' work on steel,[1] where Chernoff, of St. Petersburg, and Jullien, of

[1] "Steel: its history, manufacture, properties, and uses," 1880, p. 645.

Mr. Smart. Paris, were quoted. A red heat appeared to the Author a less misleading term, and the mild steels now produced would well sustain the bending tests prescribed if cooled from this heat, even without the planing of the edges, and would stand to be bent under the hammer instead of in the press.

Mild steel plates for steam-boilers were mostly tested for tensile strength and ductility, also for toughness and incapability of being tempered, and sometimes also for welding. The tensile strength required was usually about 28 tons per square inch, but varied according to different preferences between 26 and 30 tons, and was occasionally as low as 25 tons, and as high as 32 tons. The elongation to prove ductility, required in a test-piece of 8 inches, was about 25 per cent., and not less than 20 per cent. The ordinary test for toughness as well as ductility was, that strips should bend double cold, without fracture in the press, until the inner radius of the curve was equal to the thickness of the plates. The strips were most frequently bent under the hammer, which was a more severe test. The test to show that the steel could not be tempered, for this was a characteristic of mild steel containing from 0·05 to 0·20 per cent. of carbon, was, that the strips, after being cooled at a red heat in water at a temperature of from 80° to 82°, should be capable of being bent double cold without fracture, until the inner radius of the curve was one and a-half time the thickness of the plates. The strips for all the tests should be cut both lengthwise and crosswise of the plates, and should be planed on the edges, but the planing was frequently if not generally omitted for the bending-tests. The strips for tensile strength should be about 2 inches in width, and those for bending from 1½ inch to 2 inches. Strips from each plate should be tested; the Board of Trade required, in boilers constructed under the supervision of their surveyors, that the tensile strength and elongation should, after test, be stamped on each plate where it could easily be seen. Samples of the angles and rivets used were also subjected to tests somewhat similar to those for the plates, as pointed out by Mr. Farquharson, and in addition, the rivet-heads should bear being hammered down hot without cracking at the edges, until the diameter of the head was two and a-half times the diameter of the shank. On completion all boilers should be tested by hydraulic pressure to double the intended working-pressure, but as pointed out by Mr. Cowper, it should first be ascertained by calculation that such test shall be well within the elastic limit. During the test, deflection should be carefully noted.

Mr. Smart. With regard to the riveted joints shown in the Appendix, he did not wish it to be understood that they were all of the best possible proportions. They had only been given as samples from some of the best in use in modern practice. In Nos. 1 and 2, the proportions were those usually adopted for the thicknesses of plates given; and with iron plates treated in the ordinary method, namely, punched and unannealed, there was no doubt that the ratios of strength stated were all that might fairly be relied upon, although higher results had been obtained. With thicker plates the efficiency of joint would be much less. Mr. Longridge thought that if the strength of these joints had been estimated by calculation in the same manner as the others, it would probably have come out about 55 or 60 per cent. This, however, did not show that the method of calculation employed in the other instances was incorrect; but only that it was inapplicable in this case, a fact of which the Author was well aware, as it neither took into account the distortion of the fibres of the metal left between the holes which took place in a single-riveted joint through the cross-bending strains to which it was subjected, nor the injury done by punching. The injury from both these causes would be greater the lower the ductility of the material and the thicker the plates, as explained in the Paper, but the injury to a more ductile material like mild steel with drilled holes would be much less; in fact, Professor Kennedy, in the experiments already quoted from, with a single-riveted lap-joint of drilled steel plates 0·347 inch thick, and steel rivets, obtained in one instance a strength of 63·7 per cent. of the solid plate—a higher ratio than Mr. Longridge was willing to allow for a well-proportioned double-riveted butt joint with double straps and punched and annealed steel plates. With reference to his remark that the strength of a joint of this form, butt, double-riveted, double-strap, No. 5 in the Appendix, would be nearer 62 than 72 per cent., and that the strength of the joint, No. 4, would be nearer 58 than 68 per cent. The experiments of the Boiler Insurance and Steam Power Company of Manchester already referred to, which were carried out between the years 1874 and 1876, gave results in some cases in accordance with Mr. Longridge's figures; but an examination of the joints showed that in most cases they were not of the best proportions, although of the forms in common use at the time. The pitch of some of them was so close that no higher ratio of strength than 58 or 59 per cent. would have been possible, even although the holes had been drilled; and in others it was so wide for the thickness

Mr. Smart. of the plates, that the full strength of the metal left between the holes could not have been expected, owing to the unequal way in which, with a wide pitch, the strains come upon the plates. Furthermore, the diagonal pitch in a number of the zigzag joints was so close as seriously to impair their strength, and in most cases the plates which were of iron were punched and unannealed. The strength of some of the joints, however, approximated closely to that found by calculation, and in the other cases the loss of strength could be satisfactorily accounted for. An examination of the results of more recent tests both with drilled, and punched and annealed steel plates, convinced the Author that, if tested, the strength of the joints in the Appendix, referred to by Mr. Longridge, would closely approximate to that given in the Table.

With reference to the superiority of chain to zigzag riveting, which Mr. Longridge thought had been clearly proved by the experiments he had quoted, the Author had not omitted this arrangement of riveting from the Appendix without due consideration and a close examination of the experiments referred to by Mr. Longridge, for whose deductions he thought there was no good ground. Much light would have been thrown on the subject if Mr. Longridge had stated how the joints and plates shown by Figs. 25, 26, 27 and 28 had failed. In every case the joints and plates with the zigzag arrangement had failed in the diagonal directions, and those with the chain arrangement had failed through the straight line. An examination of the zigzag joints and plates showed that the diagonal pitch was much too close. If the first and second rows of rivets in the joints, Fig. 25, had been at least $\frac{1}{2}$ inch, and those in the plates, Fig. 27, at least $\frac{7}{16}$ inch further apart, the results would no doubt have been very different. Since these experiments were carried out, the proper ratio of the diagonal pitch to that in the straight line had been the subject of much investigation. The Board of Trade had arrived at the conclusion that to give equal strength of plate in both directions, the zigzag pitch should be $\frac{6}{10}$ horizontal pitch plus $\frac{4}{10}$ diameter of the rivet; and Professor Kennedy had mentioned, as the result of his experiments so far as they had been carried out, that the area of plate in the diagonal directions should be from 30 to 35 per cent. in excess of that in the straight line. Compared with these standards, the zigzag pitch in the joints and plates shown would be found deficient. But, if the diagonal pitch of rivets of the examples shown by Fig. 25 had been sufficient, and the plates had still failed before those with the chain arrangement, this would by no means have proved that chain was superior to

zigzag riveting. It would only have shown that the closer pitch was superior to the wider one, owing to the strains being more equally distributed and the extension more localised. The close chain riveting simply enabled the full strength of the metal left between the rivet-holes to be utilized, but there was no reason for doubting that with a zigzag joint of equal pitch the same result would have been obtained. On the contrary, as zigzag riveting appeared from its form better adapted than chain riveting for equalizing the strains along the lap of a plate, it was more than probable that a well-arranged zigzag joint was capable, with a somewhat wider pitch than chain riveting, of utilizing the full strength of the metal left between the rivet-holes, and thus of affording a higher ratio of strength of joint. Mr. Smart.

The Author entirely agreed with Mr. Samson Fox with regard to the superior strength of the corrugated flue to resist collapse both before and after pocketing; but the recommendation to close staying was made in consequence of instances having come to his knowledge of the elongation referred to. He wished, however, to take this opportunity of mentioning that, since the Paper was written, instances had been reported in which close staying of marine corrugated furnaces, of the thickness and consequent stiffness now necessary for the high pressures coming into use, had produced too great rigidity, and had given trouble by causing leakage at the joints. It would therefore be seen that there was a possibility of overdoing the closeness of the staying, notwithstanding the pliancy of the flues under compression claimed for them by Mr. Fox.

Apparently it was sometimes thought that the expansion of a corrugated flue of a given length by heat alone, and independent of the elongation due to the pressure on the end plates, would be greater than that of a plain flue of similar length; but this would not be the case, the amount of expansion in each instance would be the same, notwithstanding the greater length of metal in the corrugated flue.

Correspondence.

Mr. GEORGE P. CULVERWELL observed that previous to leaving the makers boilers were now almost always tested, firstly, by hydraulic power, and, secondly, under steam at pressures considerably in excess of the intended working limit. There was a tendency, not only with the general public but also among some engineers, to Mr. Culverwell.

Mr. Culverwell. view such tests as finally indicative of satisfactory strength or otherwise. The satisfactory strength of a boiler could only be guaranteed by the fulfilment of three conditions, namely, by good quality of the materials, by proper design and proportionment of parts, and by good workmanship. Hydraulic and steam-tests had reference merely to the latter. He had known instances, however, in which unduly high tests had been specified, whereby the joints would become permanently stressed. In such boilers as he had tested he was careful to avoid this, and he considered there was no advantage in exceeding the working-limit by more than 40 per cent. The tests should be maintained for some time, say, for fifteen minutes or longer, so as to allow water in deep double-riveted seams to creep through and show itself. He noted the Author's remark that some firms of good reputation neither fullered nor calked the seams, but relied altogether on good workmanship. In any case he would recommend that the hydraulic and steam tests be applied previous to any outside calking or fullering, otherwise there would be no guarantee that water was not lying in the joints.

Mr. Hayes. Mr. JOHN HAYES directed attention to what he considered a serious defect in the detail construction of steam-boilers, especially of the locomotive and vertical type. By reference to Fig. 10 it would be seen that, in the type of vertical boiler put forward by the Author, the plates of the firebox, both at the fire-hole door opening and at the bottom or foundation of the firebox, were worked or dished out to meet the plates of the outer casing or fire-box shell; this was bad boiler construction, and therefore to be discountenanced, as the aim of an engineer in designing a boiler should be, and was in first-class work, never to bend, work, or flange any plate, especially a firebox-plate, unless the same was from constructive or other difficulties absolutely necessary. In his opinion, the proper mode in this case was to put in solid wrought-iron rings of the full width of the water-space between the inner and the outer casing, both at the fire-hole opening, but more especially for the bottom or foundation ring of the firebox. The many advantages attending the use of solid intervening rings were so obvious, in place of bending the plates themselves, that further explanations would be superfluous; all the best locomotive and boiler-making firms inserted solid rings, and left the firebox plates straight. The only reason for the contrary being adopted was that it was somewhat less costly, and boilers so put together were made "to sell," their safety and working efficiency being only of secondary importance, hence the trouble

and disaster so frequently attending their use. Many of the evils attending the working of stationary boilers, and the destruction caused by boilers being allowed to get "short of water," could be reduced to a minimum, if not entirely prevented, by the adoption of some simple and efficient means of supplying boilers with water "automatically." This was no mere theory; he had for the past two years put the matter into practice by means of the Fromentin Automatic Boiler-Feeder, which he had successfully fitted to boilers in various parts of the country. Stated briefly, its functions were to maintain by automatic means a constant water-level in any steam-boiler to which it was fitted, irrespective of the rate of evaporation; shortness of water was therefore impossible. It was also a means by which, at the same time, the water passing into the boiler might be measured, and was a simple, ingenious, and trustworthy piece of mechanism for the purpose of boiler-feeding. Mr. Hayes.

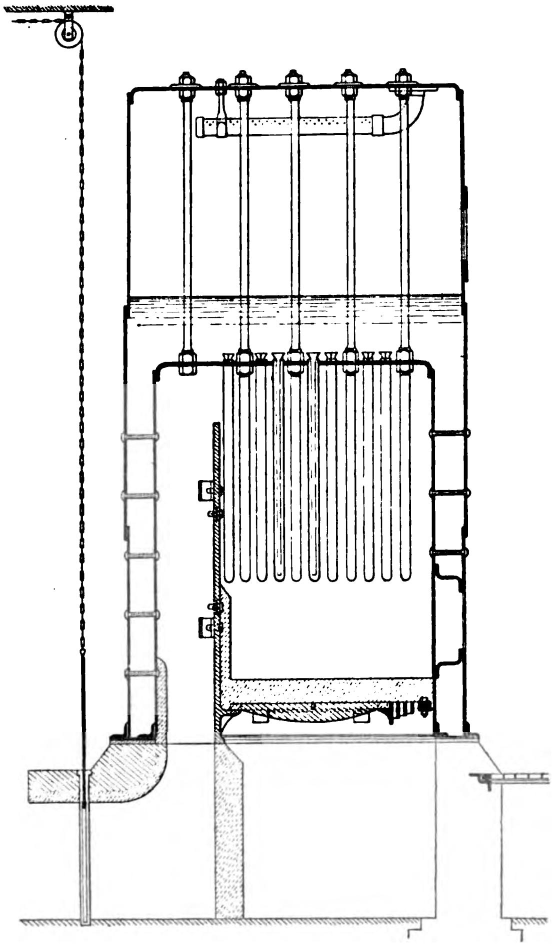
Mr. C. H. Moberly observed that the Author simply stated the fact that the steel plates used for boilers had a tensile breaking-strength of 26 to 30 tons per square inch. These limits were very properly fixed some years ago, and were now the standards used by Government and most users of steel plates. But he thought an endeavour should be made to raise the standard of strength, if this could be done with safety, in order to reap the full advantages of such an excellent material as mild steel. He had reason to believe that there would not be any difficulty in getting steel makers to produce steel plates and rivets of a tensile breaking strength of 29 to 31 tons per square inch, with an extension of 25 per cent. (or possibly a little less) in 10 inches, and, furthermore, of such quality that the steel should not harden if plunged red hot into water. This steel would be rather harder than that of lower tensile strength; but he contended that that was a positive gain, because it enabled the riveted joints of the steel plates to be made all the stronger. In furnace work the softer steel of course remained preferable. He had repeatedly found such harder steel in every way satisfactory. Rivets must, of course, be of the same quality, otherwise little advantage would be gained. The Author mentioned gusset-stays for the ends of boilers, attached by single or double angles to the shell or end-plates. He also mentioned the longitudinal stay-bolts for the ends, and Mr. Fletcher explained that these stay-bolts should be fixed with a considerable amount of sag, so as to allow the ends of the boiler to go outwards a little by expansion of the flue before they come into play. It was admitted on all hands that the ends must Mr. Moberly.

Mr. Moberly. be sufficiently flexible to allow of the necessary breathing action, caused by the differences in temperature between the several parts of the boiler. For this reason he considered the gussets attached by angles too rigid, whilst the method of preventing the rigidity of the stay-bolts by making them sag when cold, seemed very crude and unsatisfactory. At Erith, Messrs. Easton and Anderson had always adopted flanged gusset-stays, riveted to end- and shell-plates with a single row of rivets. They formerly made these of treble-worked Staffordshire plates; but of late years they had used steel plates. The riveting of these gussets had to be very carefully done to prevent leakage. But this difficulty being got over, the gussets answered admirably and lasted many years. They yielded in course of time to the repeated bending in the root of the flange. It was then an easy matter to substitute new gussets for the old ones. The Author had alluded briefly to the various forms of riveted joint. There was much need of accurate information on this subject, and he hoped some additional information would be forthcoming. The Research Committee of the Institution of Mechanical Engineers had done good service in devising riveted joints for steel plates, and he trusted would, before long, definitely fix the best form of such joints. But he feared riveted joints for iron plates were, as yet, far from being correctly proportioned. It was hardly fair to give the relative strengths of the different kinds of joints and the solid plates before the best proportions of such joints had been determined.

Mr. Olrick. Mr. HARRY OLRICK observed that the table of riveted joints would have been more valuable if the comparative strength of plates, both of steel and iron with punched and drilled holes, had been given from actual experiment. He doubted the superior strength of drilled over punched holes unless they were countersunk and the burrs were removed after drilling. He knew of one large railroad shop, about to make steel boilers, which would not be fitted with drilling-machines. His experience was that steel plates from first-class makers were more trustworthy and more readily worked than iron plates costing the same money. The joint (No. 9) shown by the Author as having the greatest calculated strength, namely, 80 per cent., had the outer row of rivets so far apart that he thought the plate could not be fullered or calked efficiently, in case of leakage. With respect to the difficulty of keeping tubes tight when held rigidly at both ends, as in locomotive or marine boilers, he suggested that if torpedo-boat boilers were made up of a number of rectangular vessels fitted with "Field" tubes, which were fixed at one end only, no trouble would occur; and, moreover,

boilers so constructed would weigh less, and take up smaller space Mr. Olrick. than a locomotive boiler of the same power. Mr. Olrick considered that a brick or clay lining around the fire-box on the top of the bars was much more necessary than a fire-clay lining to the

Fig. 30.



Scale, $\frac{1}{16}$.

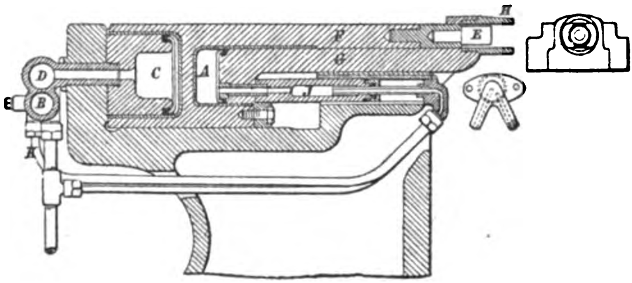
uptake of an ordinary cross-tube boiler, as his experience tended to show that this was the part of a vertical boiler to first show signs of distress, owing to the mud and other impurities in the water silting up the water-space at the bottom of the boiler, and causing

Mr. Olrick. overheating of the plates. For this reason he considered the space from the fire-bar level to the bottom of the water-space, as shown in Fig. 10, much too little. He had designed and built two boilers for the London Stock Exchange, to drive the electric-light machinery (Fig. 30). This form of boiler had no central uptake, and was less liable to damage from expansion and contraction than any other form of which he knew; and at the same time every part of both the inside and out was readily accessible for examination and repairs. This boiler had 400 square feet of surface, and easily drove engines of 60 I.HP., requiring 40 lbs. weight of steam per 1 HP. per hour at 100 lbs. pressure, being only 11 feet 6 inches high by 5 feet 10 inches outside diameter. Tubulous boilers frequently gave trouble, owing to the large quantity of sulphates and carbonates of lime, with other impurities, held in suspension in the feed-water, and which were precipitated when heated to a temperature of 300°. The proper plan to pursue, therefore, was to subject all feed-water to the stated temperature, and to pass it through filters prior to entering the boiler. As this could be done without extra fuel, beyond a very small amount due to radiation, he thought engineers should never neglect to forcibly impress it upon their clients, and so tend to minimize explosions, which were largely due to overheating of plates heavily coated with scale.

Mr. Tweddell. Mr. R. H. Tweddell remarked, in reference to the Author's contention as to the necessity of annealing steel plates after flanging, that when hydraulic-machines were employed for this purpose, the work of flanging was performed so rapidly, that the heat which the plate retained was amply sufficient to anneal it without re-heating. The Author had also alluded to the necessity of fitting and bolting the plates well and closely together before riveting them. Mr. Tweddell showed, in Fig. 31, how this was done mechanically by hydraulic pressure, and without any dependence on the skill or attention of the workman. The riveting-machine had two cylinders, one contained within the other. The ram G carrying an annular plate-closing tool H, which surrounded the cupping die E, moved in advance of the ram F, which carried the die E. When the rivet was ready to be closed, pressure was admitted by the valve D into the cylinder C, when the ram F advanced in the usual way. The water in the cylinder A being in constant communication with the accumulator, until the pressure in this chamber exceeded that in the accumulator, owing to the tool H coming against the plate, the full power due to the area of the ram was exerted upon the plates, and they

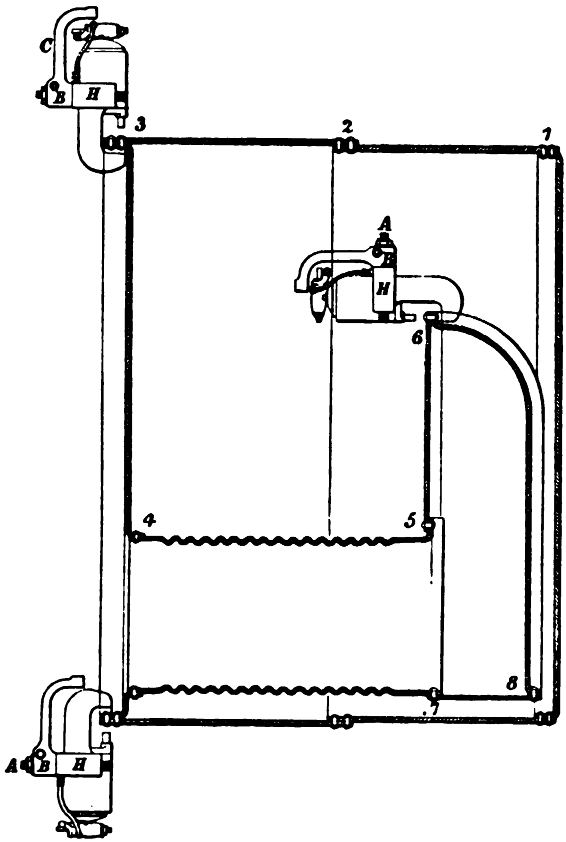
Mr. Tweddell.

FIG. 31.



Scale $\frac{1}{12}$.

FIG. 32.



Scale $\frac{1}{48}$.

Mr. Tweddell. were thus pressed together, before the operation of forming the rivet head began; this also prevented any possibility of the formation of collars or washers between the plates alluded to by the Author. The opposing cupping die in the other arm of the riveter was not shown, but it was of the usual kind, although in some instances the plate-closing gear was put upon this also. The general arrangement of such machines had been fully described in his Paper, read before the Institution in 1883.[1]

In reference to the effects of "punching" on steel plates, it was nearly certain that the action of punches and shears worked by hydraulic pressure was much less injurious to the plates than that of geared machines, and he thought the late Sir William Siemens had stated that the most searching crucial test that this homogeneous metal could be put to, was to punch it.

As to calking, this would be or ought soon to be a forgotten art, and would be less and less required the more mechanical riveting was applied. Fig. 32, p. 183, represented a marine boiler with the plating and joints, so arranged, that all the joints could be closed by hydraulic riveting-machines, some of these joints were such as could not be made tight by hand without being calked; but by means of the portable riveter this could now be done, so that calking was no longer required, and at the most a slight fullering was all that was wanted. He should add, however, that another reason why this was now possible, was the extreme accuracy of the flanged work when effected by machinery. In comparatively light work neither calking nor fullering, as the Author observed, were needed for the reasons above given.

Mr. Webster. Mr. JOHN J. WEBSTER was of opinion that the statement about the comparative strength of plain and corrugated flues needed further explanation, and that full details of the experiments should be given before accepting such extraordinary results. When the corrugated flues were first introduced to the public in 1878, some experiments were made at the works of the Leeds Forge Company, to determine the comparative strength of plain and corrugated flues. A description of the experiments and of the apparatus used was given at the time,[2] and in the absence of further information he assumed that the tubes exhibited at the North-east Coast Exhibition, and alluded to in the Paper, were tested either with the same or similar apparatus, and under similar conditions, the results being equally extraordinary. The apparatus consisted of a

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 64.
[2] "The Engineer," 29th March, 1878.

Mr. Webster.

cylinder about 8 feet long, made of plates $1\frac{1}{8}$-inch thick, bound with five iron hoops 5 inches by 3 inches, with end-plates 5 inches thick, and stayed longitudinally by external bolts $2\frac{1}{2}$ inches in diameter. This cylinder acted as the shell of an ideal boiler, the end plates being prepared at each extremity to receive the tube or flue to be tested, leaving a water-space of a few inches between it and the shell; the whole was made water-tight by suitable packing in the rings. Water-pressure was then applied, and the deflection and crippling pressures were noted. This apparatus was designed to facilitate the removal of one flue after being tested, and the insertion of another. At first it would appear that this was a legitimate comparative test, and that both flues had been tested under exactly similar conditions; but upon consideration it would be found that the conditions were strongly in favour of the corrugated flue, and most unfavourable to the plain tube. Mr. Webster did not wish to underrate the value of the corrugated flues, for they had been proved to be undoubtedly strong. He was, however, of opinion that the published results of the comparative strengths of the two flues needed confirmation, and that the conditions of test were not identical. In the first place, the effective diameter of the two tubes was not the same. That both tubes might enter the testing apparatus, it was necessary for them to have exactly the same external maximum diameter, therefore the effective diameter of the corrugated flue was less than that of the plain flue by the depth of the corrugation, or say 2 inches, which would make a considerable difference in the crippling pressure. In the next place, the corrugated flue was in its strongest possible form, and was not dependent upon any system of rings or joints for increased strength, being entirely self contained, but the plain tube was in its weakest form. No one would fix a tube 8 feet long, and more than 3 feet in diameter, into any boiler working at a moderate pressure without stiffening rings, therefore on this ground, for the test to have been a fair one, the plain tube should have had the usual stiffening rings, one or two according to the pressure. Again, the tested tubes were not fixed at the ends, to enable them to be removed and replaced more easily; and this would affect the strength of the flues in about the same proportion as the relative strengths of a column when fixed or rounded at the ends. It might be urged that this objection could not hold, as both flues were under this condition; but it was probable, from the peculiar yielding nature of the corrugated tubes longitudinally, the fact of fixing the ends would afford little if any assistance, and it certainly could not give them the same support as it would to the

Mr. Webster. plain tubes. Taking all these points into consideration, he was of opinion that if a circular plain tube properly stiffened, fixed at the ends, and of the same diameter as the mean diameter of a corrugated tube were tested, the crippling strain would approach much nearer to that of the corrugated flue than the results quoted in the Paper.

The greater heating surface which the corrugated flues no doubt possessed could not be of much value, for the effective heating surface was hardly increased, the useful effect varying with the angle of the plate; and the greater expansion of the corrugated flue when heated must be rather a dangerous feature, notwithstanding the proposed additional longitudinal stays. As an illustration of the pitting and grooving of plates being due to the nature of the water, he gave an instance which occurred in his own experience. Two sets of boilers, of four in each set, were made at the same time about five years ago from the same design, and by a good maker; one set was worked with water pumped from the dock, and the other was worked with water supplied from the town mains. The latter boilers were still in good condition, but the former had given trouble about twelve months after they were started.

Mr. Smart. Mr. D. S. SMART, in reply upon the correspondence, remarked that the statement on p. 109 of the Paper appeared to have been misread. It was not there stated that calking or fullering had been given up by some makers, but only that they did not consider it necessary to calk or fuller the seams on the inside of a boiler.

Exception had been taken by Mr. Hayes to the dishing or expanding of the fire-box of the vertical boiler, shown by Fig. 10, round the bottom and at the furnace door. If the method preferred by Mr. Hayes had been shown, it would scarcely have represented "The Modern Practice in the Construction of Steam-Boilers." The insertion of a solid ring round the bottom of the fire-box of this type of boilers, though once the common practice, was now almost unknown. As it was a more expensive method than dishing, and had no real advantage over it, the change was not to be regretted. It might be said in favour of dishing that the rivets required were shorter and more easily made to fill the holes, and there was only one joint to be kept tight instead of two joints. The advantage of dishing at the furnace door was very evident. Under the old arrangement with the solid ring, the great thickness of metal round the opening was a constant source of trouble, through the fracturing of the furnace-plate at the edges owing to the overheating and the sudden contractions on opening the door. The

Mr. Smart. dishing removed the joint somewhat out of the direct impact of the flame; and it would be observed from the sketch that a thinner ring was still inserted to reserve a water-space, and this also prevented stress upon the plate from further dishing, although a good quality either of iron or mild steel would sustain without injury considerably greater punishment than was required in this operation. The dished plate at the furnace door had the further advantage of permitting a fire-door frame to be inserted, when thought necessary, with provision on the fire-box side for retaining a fire-clay covering over the joint.

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10 February, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion upon the Paper on "The Modern Practice in the Construction of Steam-Boilers," by Mr. D. S. Smart, occupied the whole evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2034.*)

"Notes on Electric Blasting in China."

By Claude William Kinder, Assoc. M. Inst. C.E.

The whole subject of electric blasting has been recently set forth in a lecture delivered to the members of the Institution by Sir F. A. Abel, Hon. M. Inst. C.E.; yet the Author nevertheless hopes that the following notes of his practical experience, extending over the last six years, may throw additional light upon the question. Most of the English literature on the subject is due to officers in Her Majesty's service, and a few pamphlets published by rival dealers in exploders and fuzes. That many of the alleged difficulties are unfounded, is proved by the results obtained at Kaiping, and by the readiness with which Chinese coolies make daily use of the apparatus about to be described.

In 1878 the Author was appointed Resident Engineer to the Chinese Engineering and Mining Company of North China, then just started under the late Mr. R. R. Burnett, M. Inst. C.E., as Engineer-in-Chief. As only native labour was to be had, and this entirely unskilled, it was resolved to mitigate the dangers of blasting as much as possible by the exclusive use of electric ignition in shafts and stone drifts. The rock consisted of very hard sandstones and tough shales, which required the use of machine-drills, in places where native labour otherwise would be of little effect. Three Cornish sinkers acted as foremen to the shifts, and although they were fresh from large mines in England, none of them had ever heard of electric blasting. The failures which at first occurred naturally damped their belief, but they nevertheless soon became staunch converts. It is hoped that the following concise description of the apparatus will be of service both to practical men and to experimentalists.

Exploders.

The first machines used were Siemens' dynamo-exploders, chosen on account of their great durability, and freedom from being

affected by moderate dampness. It is undoubtedly the best exploder extant, provided suitable fuzes can readily be purchased in an absolutely fresh condition. Under the description of fuzes, it will be noticed why the Author has been unwillingly forced to discontinue the employment of this machine, and to fall back upon another type.

The dynamos are of two kinds, commonly known as "high tension" and "quantity," the first giving a short and intensely hot spark which ignites a chemical priming; the latter a continuous current which heats a platinum wire to incandescence. The first cost of these machines is greater than others, but their durability, and excellent construction, makes them the cheapest in the end.

The "high-tension" exploder, Plate 2, Figs. 1 and 2, consists of a small Siemens dynamo enclosed in a suitable wooden box. The peculiar cam-motion K, below the commutator C, is to enable the electro-magnets M M to become excited by a current generated from their own residual magnetism; the lever L is thus held down during two revolutions of the handle; on its being allowed to rise by the notch cut in the cam, the strong current accumulated in the magnets is permitted to flow to the line by means of the terminals T T; or should these not be in communication, by a suitable conducting medium, the current is absorbed in a mica protector P, placed under the bed of the machine. In case of the handle being incautiously turned too often, this protector will be pierced by the spark generated, at once giving a vent to the current and saving the machine-coils from total destruction. This has never happened in the Author's experience.

Fig. 4 indicates the path of the current during the period of excitation of the magnets; Fig. 5 shows the position of the lever and diversion of the current at the moment of discharge at the terminals T T; the dotted line represents the conducting medium, and P the protectors. The adjusting-screw is so placed that the separation of the points $x\ y$ is only momentary. As these contacts are all liable to sparks, they are carefully tipped with platinum.

With ordinary care, the machine requires little attention beyond slight cleaning and lubrication of the working parts. In case of the spark becoming feeble during damp weather, the cloth pads in the protector are taken out and dried; this operation needs sufficient care to prevent injury to the mica plate, but is easily done by means of a small screw-driver. The box should be constantly locked while in service, as the curiosity of the men to find out how the "fire" is made is very great, and has led to trouble.

The Author has several times experienced a severe shock at the moment of firing, and at one time the sinkers became so afraid of the "box" that they refused to use it; the difficulty was easily got over by wrapping a piece of rubber sheeting around the handle.

When many fuzes have to be fired in circuit, the handle is rotated slowly half a dozen times before attaching the leading wires to the terminals (this is to additionally excite the magnets). When all is ready, the handle is turned very gently till a click is heard; two quick revolutions will then fire the charge. In some cases four turns are necessary, but more than this should never be given.

A simple device for firing two series of holes simultaneously by two machines is shown in Figs. 14 and 15. It consists of an upright post and a shelf, on which the exploders are placed facing each other; disks are then attached in lieu of handles, with cords wound upon them. These cords unite and go over a top pulley, the end hanging free. On this being pulled, the exploders are charged and discharged with great rapidity; and if the disks are properly marked and fitted, the explosions are simultaneous. This system acted perfectly for upwards of fifty holes, resulting in a great saving of time and certainty of ignition, due to the moderate number of fuzes attached to each machine.

The "quantity" exploder (Fig. 3) strongly resembles the one above described; but electrically there is a considerable difference, as the machine has to produce a continuous flow of electricity through the fuzes until they become sufficiently heated to cause ignition. To procure this the magnets M M are wound with coarse wire, and the cam arrangement is dispensed with. The key Q, at the top of the machine close to the terminals, enables the magnets to be considerably excited by the passage of the current through the resistance coil of fine wire placed at P, Fig. 5. On the depression of the key (Fig. 7) the coil P is cut out of circuit, and the current proceeds to the line; if there is no communication between the terminals, all generation of electricity will cease; while, if the key be left up, the coil will be fuzed by careless turning, instead of more important parts of the machine being destroyed.

The great cost of fuzes for this type of exploder renders its adoption very limited; but as it can be used with very defective insulation, and the platinum fuzes keep well in any climate, it is a valuable appliance, especially in very wet shaft-sinking. As many as twenty-two holes have been fired simultaneously; but the

machine needs skilful handling, and the circuit should invariably be tested with a galvanometer.

The machine is used thus:—the left hand is placed on top of the box, with the thumb over the firing key K. The handle is turned a few times moderately quickly, and the key then pressed; great resistance is felt, which must be overcome by applying more power, when the explosion takes place.

The ingenuity shown in the construction of both the above machines cannot be too highly commended; and it is to be regretted that rival machines, as hereafter described, are not as well constructed.

The Silverton battery consists of a box containing six cells, each 9 inches by 16 inches by 3 inches, constructed on the Leclanché principle; the porous jars being replaced by hard felt. It is used in place of the last-named exploder, but cannot fire more than ten fuses under favourable conditions. The pressure of the firing key is all that is required to cause ignition, so that its actual manipulation renders it the simplest means of blasting. The high cost of the fuzes, great weight, bulk, and moderate powers, stand in the way of its frequent employment.

Bornhardt's frictional exploder[1] is shown by Figs. 8, 9, 10, and is of the double-plate pattern, capable of giving sparks $2\frac{1}{2}$ inches in length with thirty turns of the handle, in a moderately dry atmosphere. It consists of a zinc box containing the ebonite disks, catskin rubbers, and glass Leyden jars, which box is again enclosed in one of wood, suitably pierced for terminals T T, firing key F, and handle H; the last two holes are furnished with stuffing-boxes to prevent the entrance of damp air, which will at once arrest the generation of electricity. The disks D D are about 12 inches in diameter, by $\frac{3}{16}$ inch thick, rotated by means of gearing contained in G. The friction caused by these disks rubbing against the pads P P generates electricity, which is collected by platinum points connected with the interior of the Leyden jars L L. The metallic lining of the case being placed in connection with the pads and outside coating of the jars, on contact being made by means of the lever N, Fig. 8, the discharge will take place through the line-wires connected to T T, or through the testing scale S, provided the chains are placed as in Fig. 9. The scale consists of sixteen brass studs, so placed as to cause a

[1] The Author deems it best to give a more complete description of this machine than is afforded in an abstract from Mr. Jutier's paper in the "Annales des Mines." Minutes of Proceedings Inst. C.E., vol. lxi., p. 404.

spark to leap from one to the other, and the number of turns required to give this effect is a sure test of the condition of the machine. At Kaiping it averages five to six in winter, and nine to twelve in summer, owing to the excessive dryness of the former, and dampness of the latter season.

After testing the machine, which must invariably be done before firing, in order to judge how many turns are necessary, the leading wires are attached to the terminals, and the handles rotated the required number of times; a sharp push of the key F will discharge the jars and fire the fuzes. The usual number of holes varies from twelve to twenty-seven; the turns in winter being from fifteen to twenty-seven, and in summer from twenty-five to thirty-five. Excellent results are now daily got by two of these exploders. In winter they want cleaning about once a month; and the fur pads are taken out, well brushed and dried in the sun. In summer this must be done somewhat oftener, care being taken to choose a bright sunny day. This exposure to a drying atmosphere will in a few minutes cause it to give a good spark with from five to seven turns, when it should be quickly screwed up and kept in a dry room until wanted. In each instrument, two paper packets of charcoal are placed to absorb moisture.

Ladd's frictional exploder is shown in Figs. 11, 12, and 13; considering its light weight and bulk, it is the most powerful exploder in existence. It consists of a teak box containing an ebonite drum B, in which the whole of the essential parts are enclosed. A single ebonite disk D, 12 inches in diameter, is employed in conjunction with a leather pad P, coated with amalgam. The collector C is of sheet brass almost touching both sides of the plate, S being a piece of oil silk attached to the pad. The condenser, which acts the part of the Leyden jars of the Bornhardt machine, is placed below, and consists of disks of tin-foil, separated by a sheet of ebonite. This part of the apparatus is allowed to rotate about one-quarter revolution, governed by the terminal screws T K, and the two stops P P connected respectively with the tin-foil sheets of the condenser. In charging, the stop M comes against the terminal T, thus cutting out all connection with line; to discharge, the handle is brought sharply back, causing the stops P P to assume the position shown in Fig. 11. This machine, although very effective, is somewhat troublesome, owing to the use of amalgam, and the rapid deterioration of the oil silk; its high price is also an obstacle, and one which the simple construction does not account for.

The firing movement, which is copied from the American

machines, requires only one hole in the case to be protected from the influence of the atmosphere, and permits of great simplicity of construction. It is unfortunate that makers do not take more care in the manufacture of frictional exploders, and thus prevent many of the difficulties which arise solely from bad workmanship. In the Bornhardt type, the revolving gear is too weak, and the wooden collectors are so badly put together, that they come to pieces when moderately shaken, while the wire points injure the disks from want of steadiness and suitable attachment to the sides of the casing.[1] The disks should permit of easier removal for polishing, which would conduce to keeping the machine in better order.

No kind of exploder can be kept long below ground without its electrical efficiency being impaired; this especially applies to all frictional exploders.

Leading-Wires.

The leading-wires used have been of three kinds, as described in Table II. and shown in Fig. 21. The three-strand type is undoubtedly the best, and in the long run is cheapest, owing to its excellent soft rubber insulation and great flexibility which prevents it being easily damaged by the explosion. A return wire is invariably employed when many shots have to be ignited; but if proper care be taken to keep the wires close to the roof of the drift very little injury will result. The machines are generally supplied with two leading wires of 70 yards each. These with care will last several months; but they often need slight repairs, which are easily effected by means of gutta-percha and tape soaked in Stockholm tar.

The reels are made of wood, Fig. 16, the inside ends of the wires projecting through the hollow axle; and, if the leading wires are tied together at intervals of 16 feet, no difficulty will be experienced from kinking or entangling on a single reel.

Naked wires hung on insulators have been employed; but although well enough for low tension, they cannot give good results in the damp atmosphere of a mine, when any form of high-tension fuze is used.

Fuzes.

The fuzes sent out with the Siemens tension-machine were unable to withstand the effects of the voyage to China, and were

[1] The Author is aware that there are reasons to avoid such attachments, but he has fitted them with good practical results.

therefore useless. In appearance they closely resembled the Austrian pattern, but were primed with a mixture of nitro-glycerine, chlorate of potash, and charcoal.

After this failure, which almost put a stop to electric blasting, it was decided to procure Abel fuzes made by Ladd; these arrived after considerable delay, and proved to be excellent when unaffected by long storage or an unusually damp season. This fuze is remarkable for its good insulation and sensitiveness; being thoroughly well made it is not easily injured by rough handling in the mine.

The priming compound can only be made by experienced chemists, as the chemicals have to be specially manufactured by a very delicate process.

The construction of the fuze is shown in Fig. 18. The wires being cut to a suitable length according to the depth of the hole, the ends are bared, and a small piece of double copper wire, made expressly for the purpose, is attached, thus forming the tip E. The joints at F are carefully insulated with gutta-percha, and the end is inserted in the paper cap G, containing the priming mixture. A small wooden tube A is now placed over the end, cemented at B, and after being charged with powder, the whole is sealed with mastic at E; or, if for use with dynamite, a detonator acts as a plug.

The Austrian fuze, Fig. 19, is primed with a composition allied to that of Abel; but the construction is totally different. No special wire tip is used, but instead, the long wires are brought together at the end by means of a sulphur cylinder B cast around it. A metal cap A containing a small piece of gun-cotton at C, together with the priming, is placed over the tip, thus completing the fuze. Although the Austrian fuzes appear incapable of standing a sea voyage to the East, and do not permit of very rough handling, it is certain that on the Continent, when fresh from the maker, they give excellent results if care be taken in the tamping.

Owing to a very large number of Abel fuzes having been damaged, it became necessary to re-prime them. After numerous experiments it was found that several easily-made compositions acted well when used with a frictional exploder; but none could be found to give good results with the dynamo. This was very disappointing, as the Siemens machine had to be laid aside, and the more troublesome Bornhardt exploders used instead. They have been in daily use for over two years, and have given great satisfaction.

The fuzes now employed are manufactured at the works, the Abel type being adopted, as it is superior, although slightly dearer in first cost than those made on the Austrian system. The priming consists of a mixture of equal parts by weight of chlorate of potash and black sulphide[1] of antimony. These are carefully ground together in a small mortar until no white streaks are visible. The hands must be protected, so that in case of explosion due to the presence of grit, they may not be injured. The addition of charcoal makes the composition far less liable to ignition from friction, but at the same time more sensitive to moisture.

A quantity of 2·5 grams is sufficient for over thirty fuzes. The priming described is one highly recommended by French chemists for electrical purposes, and with slight modification is largely used by artillerists in the British service for friction-tubes.

After the wires have been arranged, and just previous to capping, they are tested by means of a current from a dynamo exploder, and if a fair spark results, the fuze is finished by putting on the paper cap about half filled with priming. A coating of shellac dissolved in spirits of wine greatly assists in the preservation of the cap.

At one time these fuzes were issued for service without any wooden shell, A, Fig. 20; but it has been found by experience that the preservation of the priming is favourably influenced by keeping it surrounded with fine gunpowder, no doubt due to its absorbing any moisture which would attack the otherwise unprotected priming.

A Chinese boy, receiving about 20*s*. a month, keeps all the electric gear in order, besides making over sixty fuzes a day.

The wire tipping takes up most of the time, and requires considerable dexterity, which is easily acquired after a few days' practice. In the Abel fuzes, it was found not only that the priming became caked from moisture, but that the joints were short-circuited by rust, destroying the insulation. This latter circumstance is certainly an argument in favour of the use of copper wires exclusively.

The low-tension platinum fuze, Fig. 17, is for use with quantity-dynamos and the galvanic battery. The long iron wires are similar to those used for the Abel fuze, the bare ends being thrust through two holes bored in a little cylindrical plug of wood B; the bridge of fine platinum-wire is placed between the points

[1] The red sulphide is quite unsuitable.

around which a small piece of gun-cotton is tied. A wooden shell A is fastened over the end, and filled with gunpowder, which is sealed with cement at E.

In spite of apparent extreme simplicity, their manufacture is very costly and difficult; for unless the resistance of each fuze is identical, simultaneous firing is impossible. As the bridge wires weigh only 0·21 grain per yard, it will be readily understood what great delicacy is required at the hands of the fuze-maker.

The wires should be invariably twisted together, and the fuze kept straight, as coiling for packing injures the gutta-percha insulation, especially in very dry situations. Iron wires are preferable to copper, as they remain stiffer in the hole, permitting of easy tamping, and are besides far less liable to kink. Copper wire is exclusively used on the Continent. It is less trying to the fingers of the blaster, and the connections are more neatly made. Unless fuzes can be readily obtained shortly after manufacture from trustworthy makers, it is wisest to adopt the method above described, and only make use of the freshly primed article, thereby becoming independent of delay in transport, long storage, and risk of receiving old stock.

It is much to be regretted that the Abel priming is so exceedingly difficult to make; and it is to be hoped that before long some compound will be found, which while giving equally good results, will possess more stability, or permit of easier manufacture by less skilled hands.

The requirements of a good fuze are as follow:—

The priming should be unaffected by ordinary atmospheric moisture; it should be sufficiently sensitive to permit of not less than thirty holes being fired simultaneously; incapable of being exploded by induction currents; incapable of detonation from blows or pressure; and so made as to be easily tested before use.

True the low-tension platinum fuze fulfils most of these conditions, but the great cost is prohibitive of its use except for very important and special purposes.

BLASTING.

The gunpowder, which is invariably inclosed in paper cartridge-cases, is manufactured at the Imperial Arsenal, Tientsin. The cases are made by boys at the works, and consist of three thicknesses of Japanese paper dressed with a composition consisting of 12 lbs. of tallow, mixed with 10 lbs. of resin and 6 lbs. of beeswax. When the electric fuze is used it is placed about one-third

from the top of the cartridge, filled round with powder and the mouth drawn up tight by a piece of scrap fuze-wire. These cartridges have been ten hours under deep water and have remained perfectly good; the tough Japanese paper being a cheap and excellent substitute for the rubber skins often used in wet shafts.

The tamping consists of pellets of a mixture of soft and hard clay (Fig. 22), a large stock of which is constantly kept in readiness. When the holes are all charged, two of the best hands remain to connect the fuze wires, while only one person is supposed to be present at the last moment when the leading wires are attached. This is not only for safety but because a clear view is absolutely necessary. The fuzes are invariably coupled up in direct circuit, which practically is quickest and most reliable, and easily understood by an ordinary native miner.

The Author has personally tried the various group systems, but could get no better results underground, although an improvement was noticeable in office experiments. It is useless to introduce any extra complications so long as thirty holes can be fired by the direct method.

Missfires occur at intervals, but they rarely cause serious damage to a blast, as they almost always occur in those fuzes situated nearest the leading-wire ends, and consequently in the outside holes.

Immediately after a blast an examination should be carefully made for unexploded cartridges, which are sometimes blown out.

Precautions against Accidents.

Although electric blasting is much safer than any system of time fuze, yet after a few successful rounds have been fired, the men who before feared electricity more than dynamite, become too careless in its use, and thus accidents have happened which would not occur with reasonable care.

Mowbray, in his account of the Hoosac tunnel, refers to two fatal accidents which were not due to this cause; for at that time the danger incurred by handling the wires under certain conditions was not understood. Premature explosion was caused in each case by the victims, who wore rubber boots, becoming charged with electricity due to the use of highly compressed air employed for the ventilation.

These accidents led to the following orders being issued: "Let a blaster, before he handles these wires, invariably grasp some

metal in moistened contact with the earth, or place both hands against the moist walls of the tunnel. Before taking the leading wires to the electric-fuze wires let the bare ends of the leading and return wires be brought first in contact with themselves, and then in contact with the moist surface of the tunnel, and before inserting the armed cartridge, let him unite both of the uncovered naked wires and touch with them a metal surface having good ground connection. Above all, do not ventilate, by allowing a free blast of air through a rubber connecting-pipe, until after the electric connections have been made and the blast fired."

Mr. Jutier, in his Paper before alluded to, gives an account of a severe accident, owing to the blaster having laid a packet of dynamite on the top of a frictional exploder; on firing the blast, this dynamite exploded, resulting in the death of three men standing near.

Although several attempts have been made to explode dynamite by means of an electric spark, none have succeeded, as the dynamite always burnt away. Nevertheless it is wisest to place no explosives near any electrical machine capable of generating strong currents.

The same writer also mentions a premature explosure due to the careless tamping of a charge, whereby the electric-fuze priming was detonated by pressure of a hard block of compressed powder.

Only two accidents have occurred at Kaiping: one, where the miner attempted to forcibly pull out a cartridge by the fuze-wire; the other, because the man was so ignorant as to bore out the cartridge with a hammer and drill. The first was undoubtedly owing to the detonation of the fuze; the latter was, probably but not necessarily, due to the same cause.

The amount of blasting carried on by the company in mines, quarries, and railway cutting, can be estimated by the following figures:—

		lbs.
Explosives used—	No. 1 dynamite	18,950
	Blasting gelatine	625
	Musket powder	57,600
Shots fired—	Electric fuze	39,202
	Bickford fuze	15,420

Accidents with time-fuze have been very common, as the miners will not wait a reasonable time after a hang-fire, and sometimes remain near too long after igniting fuzes.

Quantities of best double Bickford tape have been destroyed by damp, although soldered up in zinc drums.

Blasting accidents have been as follow:—

Fuze.

Bickford . . .	9 accidents . . .	1 killed, 13 injured.
Electric . . .	2 „ . . .	None, 2 „

Explosive.

Dynamite . . .	3 accidents . . .	3 killed, 7 injured.
Powder . . .	None.	None. None.

The dynamite accidents resulted from boring into unexploded cartridges at the bottom of holes.

Owing to the great carelessness of the miners, who persisted in attempting to deepen old sockets, the use of dynamite had to be given up, except where an English foreman was present to examine after each blast.

Conclusion.

From the details given above it will be seen that the primary object, safety, is obtainable in great measure by means of electric blasting. In ordinary work the additional duty per hole resulting from simultaneous ignition averages 23 per cent. with gunpowder, and over 30 per cent. with dynamite. The economy, when compared with the old system, with unskilled labour and a powerful explosive, arises from the fact that the holes need not be so well placed to get good results.

It may be interesting to note that, although it is almost impossible to teach Chinese miners to bore in favourable places, none of them have the slightest difficulty in practically applying electricity with good results; a proof perhaps of the Eastern facility of imitation, and incapacity for the exercise of sound independent judgment.

With more skilled labour a higher rate of efficiency could have been attained; and large quantities of explosives have been stolen or wasted in spite of the supervision of English foremen. Although the high-tension system now occupies the front rank, it is probable that eventual improvements will lead to the exclusive use of low-tension currents, its many advantages being so obvious. It is true that cheap quantity-fuzes, with a purely chemical priming, have given fair results, but they do not conquer the great enemy of electric blasting, atmospheric moisture. Small accumulators, charged at a central depot on the surface, could be supplied to the miners as wanted; and it is likely that such a simple form of exploder may supersede all others.

It is strange that the injury caused by the simultaneous explosion of some fifty holes to pumps and pipes in a shaft, is notably less than when single shots are fired. This possibly results from the pieces of rock striking against each other, and their projective force being absorbed in collision.

The Author refrains from giving more details of the actual blasting, as such results are only of local interest, and could afford very little information to those engaged on other descriptions of rock.

The Paper is accompanied by numerous illustrations, from which Plate 2 has been prepared.

(*Paper No. 2047.*)

PART I.

"Maximum Flood-Discharge from Catchment-Areas, with special reference to India."[1]

By JAMES CRAIG, M. Inst. C.E.

THE determination of the probable maximum flood-discharge from any given catchment basin is a problem of such importance to the engineer, that it seems surprising so little attention has been devoted to its accurate solution. In the following Paper the Author has, from facts and figures obtained from the recorded observations of many engineers in India, deduced a formula based upon a mathematical consideration of the question, the proof of the approximate accuracy of which is given in numerous instances of observed floods in the basins of large Indian rivers.

The formula for maximum discharge, popularly known among the profession in India as "Dickens' formula," which is a type of nearly all formulas on the subject, is based solely upon the extent of area, thus:—

$$D = 825\ M^{\frac{3}{4}},$$

D being the flood-discharge in cubic feet per second from an area of M square miles, under certain conditions of rainfall. Now, the maximum rate of discharge cannot depend merely upon the extent of area, for a catchment basin of, say, 5,280 square feet may be either 1 mile in length measuring from the point of discharge with a width of only 1 foot, or it may be 1 foot long and ½ mile wide on each side of the same point, the mean distance of the water being ½ mile from the point of discharge in the one case and ¼ mile in the other, so that the latter would give probably twice the rate of discharge of the former, although the extent of area is identical in both cases.

The shape of the catchment-area, therefore, is an important

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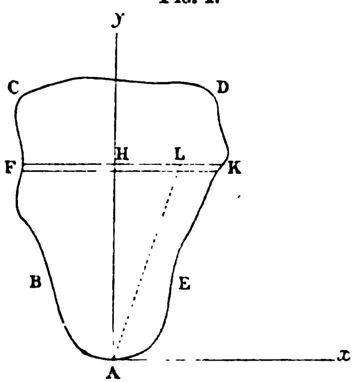
[1] Minutes of Proceedings Inst. C.E., vol. xxvii., p. 204.

factor in a formula for maximum discharge, of which fact few engineers appear to take cognizance. Some attempts at a solution of the problem based upon the length of the stream have no doubt been made, and empirical formulas enunciated; but this method of treating the subject is necessarily unsatisfactory, as the numerous bifurcations of most rivers would reduce the results obtained from such formulas to a matter of speculation, and a mere guess at the truth.

1. *Investigation of the Law of Discharge from a Surface.*—Let A, B, C, D, E (Fig. 1) represent the plan of a catchment-basin discharging towards A, the lowest point; and let the rectangular axes Ay Ax be taken, so that Ay passes through the centre of magnitude of any small zone F K, and so that $FH = HK = \frac{B}{2}$, B being the mean width of the area, the distance of which from A is y (both in miles).

FIG. 1.



Bisect H K in L, and join A L.

Area of $HK = HK \times dy = \frac{B}{2} dy$ (square miles).

Quantity of water falling upon it under a rainfall of i inches $= \frac{B}{2} \times 5280^2 \times \frac{i}{12} \times dy$ (cubic feet).

Mean distance of area H K from A, the point of discharge = $AL = \sqrt{y^2 + \frac{B^2}{16}}$ (miles).

Mean velocity of the drainage from H K towards A = v feet per second $= \frac{v}{5{,}280}$ miles per second.

$$\text{Time taken to reach A} = \frac{5{,}280\sqrt{y^2 + \frac{B^2}{16}}}{v} \text{ (seconds).}$$

Rate of discharge from H K in cubic feet per second, taking C = coefficient of discharge,

$$= \frac{440 \times \frac{B}{2} \times C \times v \times i}{\sqrt{y^2 + \frac{B^2}{16}}} dy,$$

and from the whole zone,

$$= 440 \times \mathrm{B} \times \mathrm{C} \times v \times i \times \frac{d\,y}{\sqrt{y^2 + \frac{\mathrm{B}^2}{16}}},$$

$\therefore$ Rate of discharge from the whole basin in cubic feet per second

$$= 440 \times \mathrm{B} \times \mathrm{C} \times v \times i \int_0^{\mathrm{L}} \frac{d\,y}{\sqrt{y^2 + \frac{\mathrm{B}^2}{16}}}$$

$$= 440 \times \mathrm{B} \times \mathrm{C} \times v \times i \times \text{hyp. log.} \frac{4\,\mathrm{L}}{\mathrm{B}} \left(\mathrm{L} + \sqrt{\mathrm{L}^2 + \frac{\mathrm{B}^2}{16}}\right).$$

In the logarithmic factor it is evidently possible without risk of sensible error, unless the breadth of the basin is much greater than the length which is very seldom the case, to omit the term $\frac{\mathrm{B}^2}{16}$; and for simplicity N may be substituted for the factor $(\mathrm{C} \times v \times i)$, which depends upon the meteorological and topographical conditions of the locality. The formula may therefore be stated thus:—

$$\text{Discharge in cubic feet per second} = 440 \times \mathrm{B} \times \mathrm{N}\ \text{hyp. log.} \frac{8\,\mathrm{L}^2}{\mathrm{B}}.$$

To apply the above formula to any drainage area, it is only necessary to rectify the perimeter or ridge line by means of straight lines, as C B (Fig. 2), which, with the distances C A and C B, will form triangles with their apexes at the point of discharge. The discharge of each is found by the formula with the mean width B = the perpendicular from B or C upon A D or L, which is the line joining the apex with the centre of the base C B; and the sum of the discharges from all these triangles will give the total maximum discharge from the basin.

2. *Application of the formula to River Basins, the flood-discharges from which have been observed or otherwise determined.*—In a report on the "Waterway of the Sye Bridge,"[1] General C. W., then Colonel, Hutchinson, Chief Engineer of Oudh, concludes with the remark that "in designing bridges for any of the Oudh rivers, any result based upon the apparent area of the catchment basin cannot be depended upon." He arrives at this conclusion after having compared the discharges due, according to Colonel Dickens' formula, to the apparent drainage areas of several streams with the water-ways of existing bridges, through which he assumes a maximum possible velocity of 5 feet per second. The data given in the report are admittedly only approximations to the truth, and

[1] "Professional Papers on Indian Engineering," vol. iii., p. 374. Roorkee, 1866.

in no case has it been noted that the water-ways were fully occupied during floods; but as these latter have answered the required purpose for, in some cases, forty years they may be admitted to be at any rate sufficient for the passage of the greatest floods likely to occur in their respective streams.

Fig. 2.

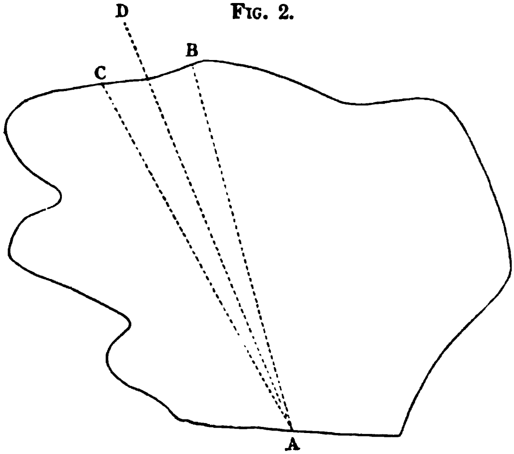


Table I. gives the data in a collected form, together with the discharges due to the drainage areas according to Colonel C. H. Dickens', and also according to the Author's, formula:—

Table I.

Name of Rivers, &c.	Catchment Basin. Area.	Catchment Basin. Mean Length.	Catchment Basin. Mean Breadth.	Discharge according to Dickens' Formula.	Capacity of Discharge of Waterway as actually existing with Velocity = 5 feet.	Discharge by Author's Formula.	Value of N from Water-way.
	Square Miles.	Miles.	Miles.	Cubic feet per second.	Cubic feet per second.	Cubic feet per second.	
Rivers Sye and Lonee at Bunnee . . .	240	30	8	50,300	64,000	23,936 N	0·27
River Lonee at railway bridge . .	120	20	6	29,910	4,600	15,479 N	0·30
River Sye at Roy Bareilly . . .	960	90	10$\frac{3}{4}$	142,300	16,500	40,893 N	0·40
River Goomtee at Lucknow . . .	2,000	133	15	246,780	20,710	60,412 N	0·34
Do. at Sultanpore .	3,600	213	17	383,420	26,000	74,500 N	0·34

From the above it will be seen that, while the quantities given by Dickens' formula are respectively about eight, six, eight and a half, twelve, and fifteen times the actual capacity of the water-ways, by assigning a value of about 0·33 to N in the Author's

formula the whole of the data may be reconciled, on the understanding that the capacity for discharge of the water-ways does not necessarily represent the actual maximum flood-discharges, and also that the data are admittedly imperfect.

The last example of a flood-discharge in an Oudh river given by General Hutchinson, namely, the Kullianee, gives a value of N about 0·79, but any comparison of this example with the other Oudh rivers above noticed would be at present unprofitable, as the character of the country through which this river flows appears to be different from that of the other basins. This stream will, however, be referred to later on.

From what General Hutchinson says regarding the Goomtee Bridge at Lucknow, it would seem that more reliance can be placed upon the data supplied for that water-way than on the others. Extraordinary floods are said to have passed through it, and the actual flood-velocity is said to have been 5·4 feet per second, from which, and from the area of water-way, a discharging capacity of 22,366 cubic feet per second is obtained, giving a value to N of 0·37. This may be considered as the value of this coefficient for very flat basins, which is the character of those in Southern Oudh.

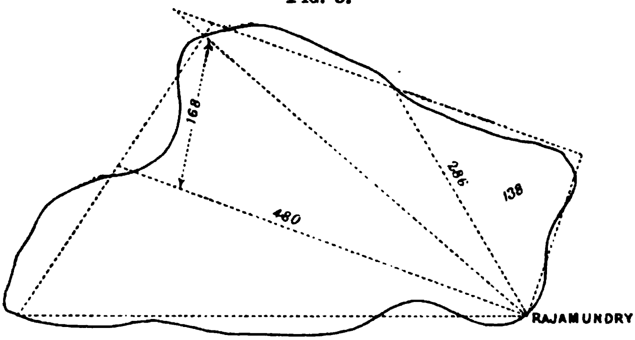
TABLE II.—VALUE of N for some of the PRINCIPAL INDIAN RIVERS, FLOOD-DISCHARGES of which have been RECORDED.

Name of Rivers, &c.	Drainage Area.	Approximate Length.	Approximate Breadth.	Observed Flood-Discharges.	Discharge by Formula.	Value of N.
	Square Miles.	Miles.	Miles.	Cubic feet per second.	Cubic feet per second.	
Ganges at Rajmahal	345,000	700	493	1,350,000	1,948,320 N	0·70
Sohan River, Lahore and Peshawar Rd.	573	27	21½	91,000	52,472 N	1·73
Godavery at Rajamundry (Fig. 3)	120,000	480 286	168 138	1,350,000	1,201,869 N	1·12
Kistna at Bezwada (Fig. 4)	110,000	460	239	1,188,000	932,800 N	1·27
Toombuddra at Kurnool (Fig. 5)	27,125	125 225	53 90	594,000	513,556 N	1·16
Cauvery at Sreerungham	28,000	230 180	51 90	472,500	518,025 N	0·91
Pennair at Nellore	20,000	180	111	359,000	378,840 N	0·95
Palaur at Arcot	3,700	70	53	112,320	154,515 N	0·73
Vigay at Madura	1,600	94	17	43,200	63,800 N	0·68
Damooda River, Ramghur	1,000	44 52 34	6½ 7½ 10	102,240	52,267 N	1·82
Do., Gurgee Nuddee	3,000	49½ 90 55	13·86 18·58 12	194,218	162,800 N	1·20
Do., Burrakur junction	4,200	76 122	14·8 25	284,389	146,014 N	1·95

Authorities.—"Roorkee Professional Papers," chiefly from vol. vii. for 1870.

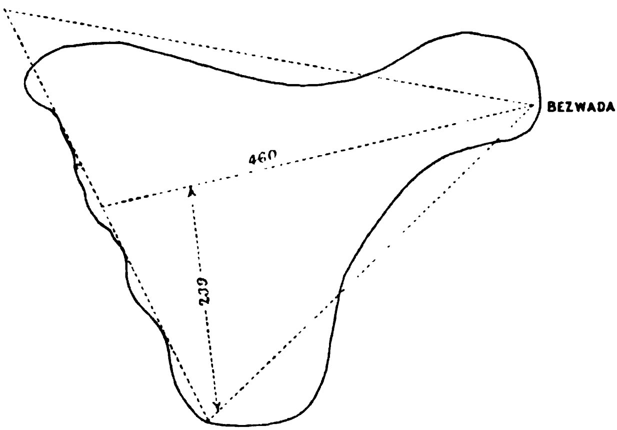
From Table II., the data in which have been prepared from various sources, it will be observed that the resulting values of

FIG. 3.



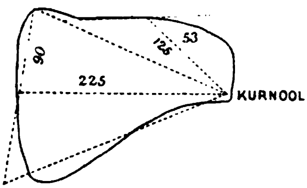
GODAVERY RIVER.

FIG. 4.



KISTNA RIVER.

FIG. 5.



TOOMBUDDRA RIVER.

N vary from 0·68 to 1·95, a variation which appears to be due to the following causes:—(1) The general slope of the country, (2) the maximum intensity and extent of the rainfall, and (3) the nature of the soil. During a period of maximum rainfall, however, these influences seem to modify one another, and the velocity of approach to the point of discharge is really the most important factor in the calculation; and as

this is undoubtedly some multiple of v, the mean velocity from the basin, instead of

$N = Cv \times i$, it may be assumed that $C = 1$ for maximum flow,

and $N = v \times i = VP$, when V is the velocity of approach to the point of discharge; so that the proposed formula may be written

$$D = 440 \times B \times V \times P \log \frac{8 L^2}{B},$$

or

$$D = \left(440 \, P B \times \log \frac{8 L^2}{B}\right) V,$$

the first factor of which becomes in consequence the area of the natural and unobstructed flood-section under all circumstances. It only remains now to find a value for P, when it will be possible to give the flood-section of any catchment basin independently of the velocity of approach. This can always be determined from a consideration of the fall of the bed of the stream, and the form of natural cross-section of the discharging channel.

Take, for example, the observed flood-discharges of the Damooda River[1] entered in Table II. At Ramghur the flood-section is stated to have been 8,477 square feet, and according to the formula the discharge is 52,267 N, and calling $N = VP$,

$$\therefore 52{,}267 \, VP = 8477 \, V$$
$$P = 0{\cdot}16.$$

Again at Gurgee Nuddee:—

$$\text{Flood-section} = 18{,}444 \text{ square feet.}$$
$$\text{Discharge} = 162{,}800 \, N = 162{,}800 \, VP.$$
$$\therefore 162{,}800 \, P = 18{,}444$$
$$P = 0{\cdot}12$$

In this case something less than the maximum flood was no doubt observed.

At the junction with Burrakur:—

$$\text{Flood-section} = 26{,}778 \text{ square feet.}$$
$$\text{Discharge} = 164{,}014 \, N = 146{,}014 \, V P.$$
$$\therefore 146{,}014 \, P = 26{,}778$$
$$P = 0{\cdot}18$$

The flood-sections are not all necessarily the highest that ever occurred; but are said to have been in some instances based upon

[1] "Professional Papers on Indian Engineering," vol. iv., p. 341. Roorkee, 1867.

information obtained from villagers, so that it is not surprising that the resulting values of P are not exactly the same; but it is thought that 0·18 may safely be taken as a constant for the maximum flood-discharge under any circumstances.

Reverting to the Oudh rivers, in the case of the Kullianee, the flood-section, as measured during an extraordinary flood, was 4,036 square feet, and the velocity ascertained by current-meter was 4·4 feet per second in the open stream.

As above remarked, the value of N, deduced from the formula and the recorded flood-discharge was 0·79, and as N = V P,

$$P = \frac{N}{V} = \frac{0 \cdot 79}{4 \cdot 4} = 0 \cdot 18$$

In the case of the Goomtee at Lucknow (Table I.), according to General Hutchinson—

Discharge by formula 60,412 N cubic feet per second.

Natural mean section of waterway = 8,277 square feet with natural velocity = 2·6 feet per second.

Discharge = 8,277 × 2·6 = 21,520 cubic feet per second—

$$\text{Value of } N = 0 \cdot 36$$
$$P = \frac{0 \cdot 36}{2 \cdot 6} = 0 \cdot 14$$

From observation of floods on the River Movena, near Akola, the mean flood-section was 5,000 square feet, and the discharge by formula would be

$$P = 440\ N \left(6 \log \frac{8 \times 18\frac{1}{2}^2}{6} \times 3\tfrac{1}{4} \log \frac{8 \times 35^2}{34}\right)$$
$$D = 27{,}500\ N = 27{,}500\ V\ P$$
$$P = \frac{5{,}000}{27{,}500} = 0 \cdot 18$$

At the Sohan Bridge, Lahore, and Peshawar Road,[1] the estimated flood-discharge of the River Sohan is 91,000 cubic feet per second, and the calculated velocity 13 feet per second, giving a sectional area of 7,000 square feet.

$$\text{Discharge by formula (Table II.)} = 52{,}472\ N,$$
$$\therefore P = \frac{7{,}000}{52{,}472} = 0 \cdot 14 \text{ nearly.}$$

If the surface velocity is meant, the resulting value of P would be about 0·15.

[1] "Professional Papers on Indian Engineering," vol. i., p. 177. Roorkee, 1864.

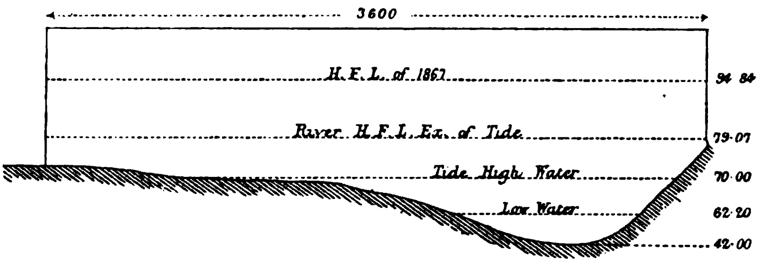
FLOODS IN THE NERBUDDA RIVER.

The Bombay and Baroda Railway crosses the Nerbudda River at Broach, within 20 miles of its point of discharge into the Arabian Sea. The crossing of the river was originally effected by an iron girder-bridge on piles, having sixty spans of 60 feet each, and the structure was opened to traffic in July, 1861.

In August, 1867, a heavy flood caused considerable damage to the approach embankments, in one of which a gap of 300 feet was made; and three bridges of 60 feet span and two of 20 feet were carried away. The result of this was, that proposals were discussed as to the necessity of providing extra water-way.[1]

In the recorded correspondence and reports on the effect of these floods,[1] the conclusion is arrived at that something like 2,500,000

FIG. 6.



cubic feet per second, or nearly double the flood-discharge of the River Mississippi, was the probable flood-discharge of the river; but the Author will attempt to prove that this estimate is about four times the actual quantity, and that this reduced estimated discharge was sufficient to produce the results observed.

Discharge of river by formula—

$$D = 440 \times 74 \cdot 5 \times N \log \frac{8 \times 510^2}{74 \cdot 5} = 335{,}667 \text{ N}.$$

Natural flood-section taking $N = 0 \cdot 18$ V = 60,420 square feet.

The section of the river-bed at the bridge is as shown in Fig. 6; but the drawings given with the papers are very imperfect, so that only approximate calculation can be made. Omitting the obstruction for low-water, which may be considered as accounted for by the other vents through the embankment, and applying the

[1] "Professional Papers on Indian Engineering," vol. vi., p. 206. Roorkee, 1869.

flood-section 60,420 square feet as found by the formula, the hydraulic mean depth of the section is about 16 feet; and as the slope of the bed is said to be 5 feet per mile, the natural mean velocity of approach $= 0 \cdot 9\sqrt{16 \times 10} =$ about $11 \cdot 5$ feet per second. The high-water level of the calculated flood-section is at about $79 \cdot 07$ feet, so that when the tidal water (which occupies a section of about 45,000 square feet of the waterway, which appears to have been lost sight of in the various reports), is at its maximum, the afflux due to these obstructions is :—

$$h = (11 \cdot 5^2 + 0 \cdot 05)\left(\left(\frac{60{,}420}{45{,}000}\right)^2 - 1\right) = 20 \cdot 21 \text{ feet},$$

which would raise the water-level at high tide to about $99 \cdot 28$ feet, or $4\frac{1}{2}$ feet above the observed flood-level of 1867.

The above figures are necessarily only approximate; but they show that the estimate of flood-discharge as obtained from the Author's formula is, at any rate, sufficient to account for the floods in the Nerbudda as described in the reports referred to. The velocity is said to have been as high as 15 miles an hour, or 22 feet per second in the centre of the stream. This was probably the surface velocity, equal to a mean velocity of about 20 feet per second, which is not unlikely to have been the case some time after the turn of the tide, seeing that the maximum high flood-level was about 50 feet above the bed of the river.[1]

Irawadi River.

In a report on the operations of the survey of the delta of this river during 1869,[1] Lieut.-Col. J. F. Stoddard, after very careful measurement of the cross-section of the river and velocity at Prome, gives the following data of observation :—

Maximum flood-section observed	=	205,617 square feet.
Maximum mean velocity . .	=	$6 \cdot 38$ feet per second.
Maximum discharge per second	=	1,312,750 cubic feet.

The area of the catchment-basin of the Irawadi is about 128,050 square miles, divisible for purposes of calculation as follows (Fig. 7) :—

[1] "Professional Papers on Indian Engineering," vol. vii., p. 352. Roorkee, 1870.

$$\begin{array}{rcrcr} L & & B & & \\ 550 & \times & 85 & = & 46{,}750 \\ 550 & \times & 110 & = & 60{,}500 \\ 400 & \times & 30 & = & 12{,}000 \\ 220 & \times & 40 & = & 8{,}800 \\ \hline \end{array}$$

Total square miles . 128,050

By formula—

$$D = 440\ N \left\{ 85 \log_e \frac{8 \times 550^2}{85} + 110 \log \frac{8 \times 550^2}{110} + 30 \log \frac{8 \times 400^2}{30} + 40 \log_e \frac{8 \times 220}{40} \right\}$$

$$= 440\ N\ \{870{\cdot}835 + 1{,}100{\cdot}00 + 319{\cdot}890 + 366{\cdot}712\}$$
$$= 440\ N \times 2657{\cdot}437$$
$$= 1{,}169{,}272\ N.$$

Making $N = V\,P = V \times 0{\cdot}18$ as before $= 210{,}469\ V$,

$\therefore$ Flood sectional area = 210,469 square feet.

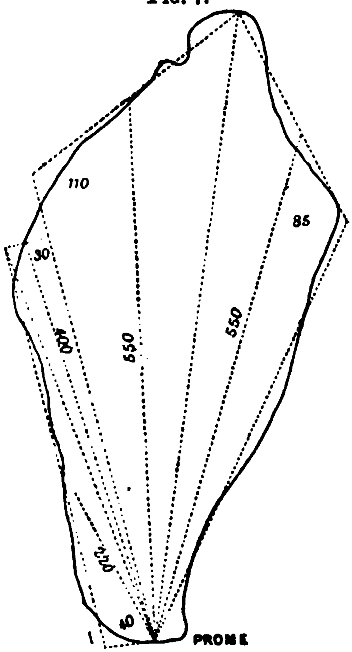
The country as to slope being probably similar to the Godavery, the value of N found for that river has been adopted, namely, 1·12.

$$\therefore N = V\,P = V \times 0{\cdot}18 = 1{\cdot}12$$
$$\therefore V = 6{\cdot}22 \text{ nearly.}$$

And discharge $= 1{,}169{,}272 \times 1{\cdot}12$
$= 1{,}309{,}584$ cubic feet per second,

all which are very close to Colonel Stoddard's figures, and for practical purposes may be considered identical with them.

Fig. 7.



Irawadi River.

From the foregoing considerations, therefore, the Author has arrived at the conclusion that the maximum flood-section of the natural and unobstructed water-way of any stream bears a constant ratio to the shape and extent of the catchment basin as given by the equation:—

$$S = 440 \times P \times \Sigma B \times \log_e \frac{8 \times L^2}{B},$$

S being the area in square feet, L and B measured from the plan of the basin as described at the beginning of the Paper, and P a constant depending upon the maximum intensity of the rainfall, which has been proved to be 0·18 for India south of the Himalayas and for Burma, so that for practical use in these countries the equation may be written:—

$$S = 80 \Sigma B \log_e \frac{8 L^2}{B}.$$

The maximum flood-discharge can be obtained by applying the sectional area so found to the cross-section of the stream for hydraulic mean depth, from which, and from the declivity of the bed the velocity of approach, and consequently the discharge, can be found in the usual way. An observed higher flood line than that given by the formula would show an obstruction in the stream at the cross-section under consideration, as in the case of the Nerbudda Bridge above referred to, and a consequent reduced velocity of approach.

The Author has purposely omitted corroborative evidence, of which he can give numerous examples, of the truth of the formula from his own observations of flood-discharges within a limited tract of country, as he considers that the examples furnished by independent observers in different parts of India are more conclusive, ranging as they do from mountainous basins like those of Northern India and Burma, over which the annual rainfall is great, to the flat plains of Oudh, and to the country traversed by the Nerbudda, where the annual rainfall is comparatively small in amount.

In conclusion, it may be observed, although somewhat beyond the scope of this Paper, that an application of the Author's formula to the catchment basins of the rivers Mississippi with its tributaries the Ohio, Missouri, and the Upper Mississippi (as accurately as the means at the Author's disposal would admit), shows that the value of P for the United States, and probably for Europe also, is 0·06 or one-third of the value found for India, which, considering the comparative duration and amount of rainfall in those countries, must be very close to the truth, as the maximum intensity of rainfall is no doubt inversely proportional to the time over which the yearly rainfall is distributed.

The Paper is accompanied by several Diagrams, from which the woodcuts in the text have been prepared.

(*Paper No. 2058.*)

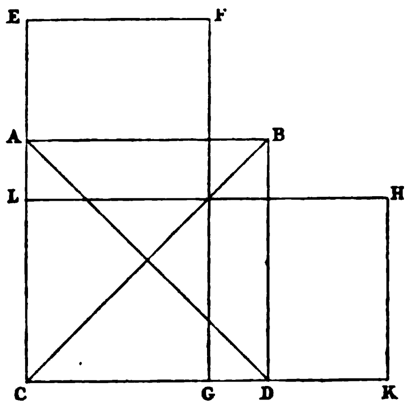
PART II.

"Mean Coefficient of Discharge from Catchment-Areas."

By JAMES CRAIG, M. Inst. C.E.

THE problem which the Author in this Paper attempts to solve may be thus enunciated. Given the quantity of rain falling over any catchment-area during the course of a year, to determine within reasonable limits of approximation the amount of water which will reach the point of discharge.

The only definite data obtainable from the plan of a catchment area, are (1) Its superficial extent, and (2) The distance of its most remote point from the point of discharge. These dimensions may be considered to be given in miles, and denote them by the symbols A and L respectively. The amount of annual rainfall in inches will be represented by R, and the mean coefficient of discharge by C.



Theoretical investigation of the subject: Let the figure A B C D represent a square area inclined towards the point of discharge C, C B being the distance of its remotest point B from the point of discharge, and let C E F G and L H C K be equivalent rectangles within C E and C K, each equal to C B.

The centre of area of each figure is at the intersection of its diagonals, and it requires no demonstration to prove that of the three figures, the distance of the centre of area of the square from the point C is the least. Now the distance of the centre of magnitude of the equivalent square from the point $C = \frac{1}{2} \times \sqrt{2\,A} = \frac{\sqrt{A}}{\sqrt{2}}$, and that of the equivalent rectangle $= \frac{\sqrt{L^2 + B^2}}{2}$, and as evaporation and probably absorption in any catchment basin will vary directly with the time taken to reach the point of discharge, it may

be concluded that coefficient of discharge will vary inversely to the time taken in the case of the rectangle, and directly, as in the case of the square, or as $\frac{\sqrt{A}}{\sqrt{L^2 + B^2}}$ (omitting the constant numbers).

Again, the coefficient of discharge will vary directly as the rainfall, so that it may finally be assumed that the coefficient of discharge may be expressed by the equation

$$N \times R \frac{\sqrt{A}}{\sqrt{L^2 + B^2}} = C.$$

Application and Proof of the Formula.—Application to the River Mississippi.

The Mississippi river with its affluents, the Upper Mississippi, the Missouri, the Ohio, the Arkansas, and White Rivers, and the Red River, traverses about two-fifths of the whole extent of the United States of America, and carries off the rainfall from a catchment-basin of 1,244,000 square miles in extent, varying in character from a rocky barren and mountainous, to a rich fertile and flat, country. Careful observations, extending over a series of years, have been made, and will be found recorded in Humphreys' and Abbot's "Physics and Hydraulics of the Mississippi River," and the following Table shows the result of the application of the Author's formula to these data—the constant N being assumed in the formula = 0·011, which appears to be about the general value for the basin of these rivers.

Name of Rivers.	Area.	Extreme Length of Basin, L.	Mean Breadth, $\frac{A}{L} = B$.	Rainfall.	Observed Co-efficient of Discharge.	Coefficient of Discharge by Author's Formula, N being taken as 0·011.
	Sq. miles.	Miles.		Inches.		
Entire Mississippi . . .	1,244,000	1,190	1,045	30·4	0·25	0·24
Upper " . . .	169,000	630	268	35·2	0·24	0·23
Missouri	518,000	1,645	315	20·9	0·15	0·15
Ohio	214,000	840	255	41·5	0·24	0·24
Arkansas and White Rivers	189,000	980	193	29·3	0·15	0·14
Red River	97,000	705	139	39·0	0·20	0·19

Application to the Cataract and Nepean River Basins, New South Wales.

A Paper by Mr. T. A. Coghlan,[1] Assoc. Inst. C.E., contains statistics regarding these two streams, and the following Table records the result of the application of the Author's formula to the given data (omitting two imperfect years).

The value of N for the basins appears to be about 0·016, and this value has been assumed in the formula.

The recorded data regarding the areas of the basins are as follows:—

Rivers.	Drainage Area.	Extreme Length of Basin.	Mean Breadth $= \frac{A}{L}$.
	Square miles.	Miles.	Miles.
Cataract	70	14·5	4·8
Nepean	284	24·0	11·84

Comparison of observed coefficient of discharge, and that resulting from application of Author's formula $N \times R \frac{\sqrt{A}}{\sqrt{L^2 + B^2}} = C$.

Years.	Rainfall.		Rainfall Discharged.		Observed Coefficient of Discharge.		Coefficient by Author's Formula.	
	Cataract.	Nepean.	Cataract.	Nepean.	Cataract.	Nepean.	Cataract.	Nepean.
	Inches.	Inches.	Inches.	Inches.				
1870 . .	64·16	64·01	43·30	43·66	0·675	0·682	0·561	0·644
1871 . .	53·70	43·36	26·54	21·23	0·494	0·489	0·470	0·430
1872 . .	40·23	34·37	10·53	6·85	0·261	0·200	0·352	0·346
1873 . .	75·08	57·49	32·58	28·40	0·434	0·494	0·657	0·578
1874 . .	54·38	42·50	27·33	17·30	0·502	0·406	0·476	0·428
1875 . .	54·36	41·28	20·42	13·79	0·375	0·334	0·476	0·415
Average .	53·99	44·28	24·14	19·54	0·447	0·441	0·472	0·446

It will be observed, from the above Table, that although on the average data the application of the Author's formula produces

[1] Minutes of Proceedings Inst. C.E., vol. lxxv., p. 176.

results which may be considered as practically identical with the observed coefficients, the difference between the calculated and observed coefficients year by year differ, and this can only be accounted for, probably, by the fluctuation from the normal of the annual temperature, the effect of which will be referred to later on.

Application to Indian Catchment-Basins—Ashti Tank.

A description of this tank has been given by Mr. C. T. Burke, M. Inst. C.E., under whose superintendence the project was carried out.[1] In this communication, at page 290, will be found a statement of observations made during the monsoon season of 1881, to determine the coefficient of discharge from the basin. This was found to be 0·18, and the Author's formula will now be applied to the data given, and the result noted :—

Discharging-area	= 92 square miles.
Extreme length of basin . . .	= 15·5 ,,
Mean breadth $= \frac{A}{L}$	= 6 ,,
Rainfall during season . . .	= 18 inches.

$$N \times 18 \times \frac{\sqrt{92}}{\sqrt{15 \cdot 5^2 + 6^2}} = 0 \cdot 18$$

$$N \quad \ldots \ldots \quad = 0 \cdot 017$$

Regarding the basin of this tank, the present local Executive Engineer for irrigation, who has kindly supplied the Author with some data, writes, "The drainage area is composed of about equal parts of black soil and high-lying bleak murram lands. The discharge into the tank has always been very small, averaging from one-seventh to one-eighth of the monsoon rainfall in ordinary years."

Now compare the above result with that obtained from the Ambajhari tank, Nagpur, constructed by Mr. Binnie, M. Inst. C.E., about 1870. The necessary data have been obtained from a Blue Book on the subject, issued by the Government of the Central Provinces :—

Drainage-area	= 6·6 square miles.
Extreme length of basin . .	= $4\frac{3}{4}$ miles.
Mean breadth $\frac{A}{L}$	= 1·43 ,,

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi., p. 288.

Rainfall (1872) . . . . . . = 43·65 inches.
Observed coefficient of discharge = 0·42

$$N \times 43{\cdot}65 \times \frac{\sqrt{6{\cdot}6}}{\sqrt{(4\tfrac{2}{3})^2 + 1{\cdot}43^2}} = 0{\cdot}42$$

$$N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . = 0{\cdot}018$$

The description of the drainage area given in Mr. Binnie's report is, that it extends from a range of low basaltic hills, and is steep, rocky, and but very slightly covered with vegetable soil.

The mean annual rainfall at Sholapur is 28·55 inches, and at Nagpur, 43·71 inches, and notwithstanding these different climatic and other conditions, the value of N is practically constant for each. Using the value $N = 0{\cdot}017$, the formula will be applied to other Indian catchment basins where observations of rainfall and discharge have been kept up.

Kotassa tank near Akote (Berar):—

Drainage-area . . . . . . = 7·4 square miles.
(Rich, fertile, and highly cultivated.)
Extreme length . . . . = 7·4 miles.
Mean breadth . . . . . . = 1 „
Rainfall (1883) . . . . . = 50·89 inches.

$$0{\cdot}017 \times 50{\cdot}89 \times \frac{\sqrt{7{\cdot}4}}{\sqrt{7{\cdot}4^2 + 1^2}} = C.$$
$$= 0{\cdot}32$$

As observed . . . . . . = 0·33

Akutwara tank near Akola (Berar):—

Drainage-area. . . . . . = 1·035 square mile.
(Rich, fertile, and highly cultivated.)
Extreme length . . . . . = 1·6 mile.
Mean breadth. . . . . . = 0·647 „
Rainfall (1883) . . . . . = 58·09 inches.

$$0{\cdot}017 \times 58{\cdot}09 \frac{\sqrt{1{\cdot}035}}{\sqrt{1{\cdot}6^2 + 0{\cdot}647^2}} = C.$$
$$= 0{\cdot}58$$

As observed . . . . = 0·53

Both the above results are almost identical with the observed coefficient of discharge.

It may be mentioned that the assumed lengths of the basins of the rivers of the United States and of New South Wales have no pretensions to mathematical accuracy, they having been measured

from the best maps available; but the Author thinks they are approximately correct, and as such, give practically accurate results, and prove that the mean discharges from catchment basins are regulated by a law which is constant for particular localities. As is suggested in the following paragraphs, by taking into consideration the question of temperature, this law will perhaps be found to prevail universally.

The Local Constant N.

The local constant N appears to contain some factor expressing the temperature of the particular locality, since the higher the temperature the greater the concentration of rainfall, and consequently the higher the coefficient of discharge.

The mean annual temperature of Nagpur, Sholapur, and Akola, near which are situated the four tanks just considered, is about 80°, and as that of the United States of America is about 50°, and New South Wales 62°, the proportion

$$50^\circ : 83^\circ : 62 :: 0{\cdot}011 : 0{\cdot}017 : 0{\cdot}016$$

ought to hold good, which it evidently does very nearly, and the formula might perhaps be capable of modification by the introduction of T, the mean temperature for the year, so that—

$$\frac{0{\cdot}00022\ \mathrm{T\,R}\sqrt{\mathrm{A}}}{\sqrt{\mathrm{L}^2 + \mathrm{B}^2}} = \mathrm{C} = \text{Universal coefficient of discharge.}$$

The Author, however, leaves the consideration of this part of the subject to other members of the profession more experienced in these matters than himself, and who have access to more statistics and records than an Indian engineer usually possesses or can readily consult.

The Paper is accompanied by a diagram, from which the figure in the text has been engraved.

ADDENDUM.

SINCE writing the above Paper it has occurred to the Author that the formula for the coefficient of discharge $N \times R \frac{\sqrt{A}}{\sqrt{L^2 + B^2}}$, therein suggested, can be simplified and perfected by the introduction of a factor expressing the time over which the local rainy season extends, and the mean daily intensity of the combined influences of evaporation and absorption. Thus, if the formula be restored to its original shape, then

$$\frac{N}{\sqrt{2}} R \frac{\sqrt{2 A}}{\sqrt{L^2 + B^2}} = C.$$

Let D be the average number of days over which the rainfall extends, and P the daily mean intensity in inches of the combined influences of evaporation and absorption during that period; the quantity run off, and consequently the coefficient of discharge, will vary inversely as these values; therefore

$$\frac{1}{D \times P} R \frac{\sqrt{2 A}}{\sqrt{L^2 + B^2}} = C.$$

Now for India the general value of $N = 0{\cdot}018$, and the resulting formula is

$$\frac{1}{93 \times 0{\cdot}84} R \frac{\sqrt{2 A}}{\sqrt{L^2 + B^2}}.$$

Here $D = 93$ days or average time, and $P = 0{\cdot}84$, or double the mean evaporation as given by L. D'A. Jackson for Akola.

For New South Wales the formula would be (taking the number of days over which the rainfall extends at 140)—

$$\frac{1}{140 \times 0{\cdot}73} R \frac{\sqrt{2 A}}{\sqrt{L^2 + B^2}} = C.$$

$D = 140$ days, $P = 0{\cdot}73$ inch.

In the United States of America, and probably Northern Europe,

$$\frac{1}{224 \times 0{\cdot}56} R \frac{\sqrt{2 A}}{\sqrt{L^2 + B^2}} = C.$$

$D = 224$ days, and $P = 0{\cdot}56$ inch; so that the formula may thus be stated in general terms as

$$\frac{1}{D \times P} R \frac{\sqrt{2 A}}{\sqrt{L^2 + B^2}} = C,$$

the general values of $\frac{1}{D \times P}$ being—

For India and similar countries .	$= 0{\cdot}0125$	Which are equivalent to the numbers $0{\cdot}018$, $0{\cdot}014$ and $0{\cdot}011$, if the factor $\sqrt{2}$ is eliminated.
„ New South Wales and similar countries	$= 0{\cdot}0099$	
„ United States and similar countries	$= 0{\cdot}0080$	

It may be observed in conclusion that the mean daily evaporation noted by Major Cunningham, R.E., on the Ganges Canal from water surface was $0{\cdot}11$ inch,

while that recorded for earth by Mr. L. D'A. Jackson in his "Hydraulic Manual," at Akola was 0·42 inch, or nearly four times that from the water surface; and since the assumed general mean intensity of the combined influence of evaporation on the plains of India has been taken at 0·84 inch, it is thought the same proportion to the figure for the United States may be adopted as Europe, thus:—

	Inch.
Mean daily evaporation from water surface	= 0·07
,, ,, ,, earth	= 0·28
,, coefficient for combined loss	= 0·56

The figures for New South Wales have been based upon Mr. Coghlan's statements that the average number of rainy days in that colony is 140.

The number of days of rainfall throughout India varies from 7 days in some stations in the Punjab to 188 days in South India, the mean being about 97.

Details of two tanks in Satara, Bombay Presidency, have just been put into the Author's hands, and although these are wanting in two important respects, viz., the exact number of days from the commencement to the end of the monsoon, and the mean daily intensity of evaporation, the results obtained by an application of the Author's formula to these may not be without interest.

Nhir Tank.

$$A = 59\cdot5;\quad L = 10;\quad B = 5\cdot95;\quad R = 22\cdot70.$$

	Days.
Duration of monsoon, 26th May to end of November .	= 187
Assume the same factor for evaporation and absorption	= 0·84

$$\text{Coefficient} = \frac{1}{187 \times 0\cdot84} \times 22\cdot70 \times \frac{\sqrt{118}}{\sqrt{10^2 + 5\cdot95^2}} \quad . = 0\cdot138$$

Observed coefficient . . . . = 0·139

Maini Tank.

$$A = 54;\quad L = 8;\quad B = 6\cdot75;\quad R = 13\cdot05.$$

	Days.
Duration of monsoon, May to September inclusive . .	= 153

$$\text{Coefficient} = \frac{1}{153 \times 0\cdot84} \times 13\cdot05 \times \frac{\sqrt{108}}{\sqrt{8^2 + 6\cdot75^2}}. \quad . = 0\cdot101$$

Observed coefficient . . . . = 0·108

(*Paper No. 2051.*)

"Experiments on the Friction of Disks Rotated in Fluid."

By Professor William Cawthorne Unwin, B.Sc., M. Inst. C.E.

The most important experiments on fluid friction which have hitherto been made are those of the late Mr. W. Froude, M. Inst. C.E., on the resistance of planks towed in water.

The experiments by Mr. Froude were on surfaces of limited extent towed in water of practically unlimited extent. It appeared to the Author that it might be useful to experiment on surfaces of virtually unlimited length moved in a mass of water of limited volume. A disk continuously rotated in one direction is virtually a plane of infinite length, in the direction of motion. If this is placed in a cylindrical vessel with flat ends, which can be approached towards or moved away from the disk, the volume of water operated on can be varied. Further, experiments made in this way afford a means of altering some of the conditions, temperature for instance, to an extent not possible in experiments on the scale of Mr. Froude's. Apart from the theoretical interest of the question of the resistance of rotating surfaces, it has great practical interest in the design of hydraulic machines. A large part of the waste of work in turbines, centrifugal pumps, &c., is the work expended on the friction of their disk-shaped surfaces in the water round them.

Suppose a thin circular disk, mounted on a vertical spindle, and rotated at constant velocity in a cylindrical vessel of water. Two methods are available for measuring the resistance to rotation of the disk. One is to measure by dynamometric apparatus the work expended in moving the disk. The objections to this method are the complexity of the apparatus, and the difficulty of eliminating other frictional resistances, such as those of the bearings of the spindle. The other method is to measure the force with which the vessel in which the disk is contained tends to rotate. The friction of the water on the vessel must be equal and opposite to the friction on the disk, when the motion is uniform. This method, the Author believes, was first employed by Professor James Thomson, in some experiments on the friction of disks, the results of which

were communicated to the Royal Society[1] in 1855. The details of Professor Thomson's experiments have not been published, and the conditions in these experiments do not appear to have been much varied. Their general result is stated thus:—

For disks with both sides rubbing in water in a flat surrounding chamber, the work expended in fluid friction is given by the equation

$$z = \frac{y^3 d^5}{90,000},$$

where z = work expended in foot-lbs. per minute—

d = diameter of disk in feet.

y = number of rotations per minute.

It is obvious that the constant here found is applicable only to one condition of surface.

Description of the Apparatus.—The apparatus used by the Author is shown in an isometric view in Plate 3, Fig. 1, and in sectional elevation and plan in Figs. 2, 3. It consisted of a strong wooden frame, on which was placed a cast-iron cistern C. A cast-iron bracket B at the top of the frame carried a three-armed crosshead *b b*, from which an inner cistern A A was suspended by three fine wires. The cross-head could be adjusted to any angular position, and clamped by the screw *a*. Adjusting screws in the arms of the crosshead permitted the cistern to be accurately levelled. The disks, which were to be rotated in fluid, were 10, 15, and 20 inches in diameter. One of them is shown in position at D D, keyed on a vertical shaft S S. This shaft was centred on conical ends, and driven by a cat-gut running on the pulleys P. The shaft was driven by a Rider's Hot-Air Engine of ½-H.P. When running at or above its proper speed, the motion of this engine is steady. At speeds below its proper rate the motion is less uniform. The speed of the engine is easily adjusted by an air-cock, and without this facility of adjustment the experiments would have been more difficult.

It will be seen that the rotating disk is contained in the submerged copper cylinder A A. The flat bottom of this fitted with very little play round the gun-metal support of the spindle. Above the disk was a flat cover E E, parallel to the flat bottom of the cylinder. The height of this could be varied by sliding it up or down, and the disk was placed so as to be in the central plane of the cylindrical mass of water. The cover E E, fitted closely to the

[1] "Proceedings of the Royal Society of London," vol. vii., p. 509.

copper cylinder, and the central hole was covered by a loose washer fitting, but not attached to, the shaft. At first difficulty was found from a pumping action set up at a certain speed, the water escaping at the edges and returning at the centre of the cover E E. Finally, a thick india-rubber ring was bolted round the edge of the cover E E, and forced against the copper cylinder. To the suspended cylinder A A was attached an index finger I,[1] moving over a graduated scale. This was always adjusted to zero before beginning an experiment, and while the apparatus was at rest. The copper cylinder was free to rotate under the action of a very small force. When the disk rotates the copper cylinder tends to rotate in the same direction. To measure the friction on the inside of the copper cylinder, which is equal and opposite to the friction on the disk, it is only necessary to carry a fine silk cord attached to the arc F over a small pulley *e* to a scale-pan G. Weights in the scale-pan balanced the friction and kept the index at zero.

To measure the velocity of rotation of the disk, a Hearson's Strophometer (H, Fig. 1), was at first used. But as this is at best a secondary standard, another method was adopted in all the experiments here recorded. A worm *w* was keyed on the shaft S S, gearing into a worm wheel W of one hundred teeth, and graduated into one hundred divisions. When the speed of the apparatus had become steady, and the friction was exactly balanced by the weights in the scale-pan, the time was observed in which fifty or more divisions of the worm wheel passed the index finger, and in which the disk had therefore made the same number of revolutions. The time was taken to fifths of seconds by a chronograph. There is only one other detail to mention, a clip brake, K K, which facilitated the adjustment of the speed. The method of making an experiment was as follows:—The Author's assistant, Mr. Nolet, took charge of the brake K K, and watched the index I. The Author adjusted the scale weights and the speed of the engine, and when steady motion was reached, took the time of a given number of rotations. When a given weight had been placed in the scale, the speed of the engine was increased till the friction roughly balanced the weight. The engine-speed was then allowed to become steady, the index being kept at zero by slight alterations of the pressure of the clip brake. While the index was thus kept steady, the time of rotation or speed was observed.

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[1] In the isometric view the copper cylinder projects above the water. This arrangement was abandoned, and the cylinder placed as in Fig. 2.

The disks experimented on were varied in the following ways:—

First, as to size. Disks 10 inches, 15 inches, and 20 inches in diameter were used. The resistance of these is nearly as 10^5, 15^5, 20^5; or as 1 : 11 : 64 at any given speed.

Secondly, as to surface. The smoothest disks were of brass, with turned and polished surfaces. A rougher surface was obtained by tallowing the brass disks. Cast-iron disks, with the surface as it comes from the mould, were also used. These were then modified by painting, by varnishing, and by attaching to them sand of different degrees of coarseness.

Thirdly, the volume of water subjected to friction was varied by altering the position of the cover E E. Three depths of chamber were tried, giving water layers 1½ inch, 3 inches and 6 inches thick on each side of the disk.

In one experiment the surface of the cover E E was roughened by attaching sand; and in another experiment a half hundred-weight of sugar was dissolved in the water in the chamber, with a view of testing the effect of a more viscous liquid.

Experiments were also made with water of different temperatures.

Theoretical Expression for the Friction of a Disk Rotating in Liquid. —Let it be supposed that the general law of fluid-friction, which applies to large plane surfaces moved uniformly in water, may be used to determine the friction of a disk. That is, supposing ω to be the area of any small portion of the disk moving with the velocity v, let it be assumed that the friction of that portion of the surface is $f\,\omega\,v^n$; where f is a constant differing for different surfaces, and n a constant, which at the velocities used in these experiments does not differ greatly from 2.

Let a be the angular velocity of rotation, R the radius of the disk. Consider a ring of the surface between the radii r and $r + dr$. Its area is $2\,\pi\,r\,dr$, its velocity is ar, and the friction of this portion of the surface is therefore on the assumption above—

$$f \times 2\,\pi\,r\,d\,r \times a^n r^n.$$

The moment of the friction of the ring about the axis of rotation is then

$$2\,\pi\,a^n f r^{n+2}\,d\,r,$$

and the total moment of friction for the two sides of the disk is then

$$M = 4\,\pi\,a^n f \int_0^R r^{n+2}\,d\,r$$
$$= \frac{4\,\pi\,a^n}{n+3} f\,R^{n+3}.$$

If N is the number of rotations per second, since $a = 2\,\pi\,N$,

$$M = \frac{2^{n+2}\,\pi^{n+1}\,N^n}{n+3}\,f\,R^{n+3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The work expended in rotating the disk is in ft.-lbs. per sec.

$$M\,a = \frac{2^{n+3}\,\pi^{n+2}\,N^{n+1}}{n+3}\,f\,R^{n+3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)^1$$

The experiments give directly the moment of friction M, corresponding to any speed N for each disk. But for any given disk

$$M = c\,N^n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where c is a constant. Hence for any pairs of values of M and N, obtained in the experiments on a given disk,

$$n = \frac{\log M_1 - \log M_2}{\log N_1 - \log N_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The mean value of n thus obtained is given for each of the surfaces tried. When the mean value of n has been obtained from pairs of results in which the speed was different, values of c for each speed were obtained, by the formula

$$\text{Log}\, c = \log M - n \log N.$$

and the mean values of c thus found are given in the Table in the Appendix. The values of n for different pairs of speeds never varied very greatly for any given disk in like conditions, nor did the values of c vary greatly for different speeds. Further, the variations from the mean value followed no regular law, so that they may be attributed to errors of observation, or to unavoidable small fluctuations of speed during the observations.

In the formulas above, f is the friction per square foot, at unit velocity, but for any given kind of surface in like conditions.

$$f = \frac{(n+3)\,c}{2^{n+2}\,\pi^{n+1}\,R^{n+3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

For comparison with Mr. Froude's results, it is convenient to calculate the friction per square foot at a velocity of 10 feet per

---

[1] If $n = 2$, from which it never differs much, this formula becomes—

Work expended in friction $= 623\,f\,N^3\,R^5$ foot-lbs. per sec.

where f varies from 0·002 to 0·003 for ordinarily rough surfaces, and increases to 0·007 for the rough surface of a metal disk covered with coarse sand.

second. But as the friction varies as the n-th power of the speed, the friction in lbs. per square foot at 10 feet per second is

$$F = f\,10^n.$$

The value of this is also given in the Table. A difficulty, however, arises from the disks not being of indefinitely small thickness. The cylindrical surface of the edge of a disk gives rise to part of the friction. As, however, this surface is not large compared with the surface of the disk, the following approximate method of dealing with it was thought allowable. A virtual radius was calculated for each disk, such that its total surface, exclusive of edge surface, was equal to the actual surface of the disk together with its edge surface. Let R be the radius of the disk, and t its thickness. Then the virtual radius was taken to be—

$$R' = \sqrt{\{R^2 + R\,t\}} \qquad \qquad (6)$$

For the disks used the following values are obtained:—

Actual Radius.	Actual Thickness.	Virtual Radius.	
Inches.	Inch.	Inches.	Foot.
10·0	0·375	10·186	0·8488
7·5	0·250	7·623	0·6353
5·0	0·375	5·184	0·4320

Discussion of the Results.

Influence of the Diameter on the Resistance.—The three experiments with disks 0·8488, 0·6353, and 0·4320 foot virtual radius, are chiefly useful for checking the validity of the assumption made in reducing the results. They do not answer this purpose in a perfect manner, because strictly the diameter of the chamber should have been reduced in the same ratio as that of the disk. Still the results agree well enough with the formula given above, to afford confirmation of the method of obtaining the friction per square foot.

From formula (1) the moment of resistance of disks with similar surfaces should vary as the $(n+3)$th power of the radius. For smooth brass $n = 1·85$. Hence the three disks in experiments 2, 20, 21, should have had moments of resistance, varying as

$$0·8488^{4·85} : 0·6353^{4·85} : 0·4320^{4·85}.$$

That is, as

$$1 : 0\cdot2454 : 0\cdot0378$$

The actual moments of resistance were as

$$1 : 0\cdot2887 : 0\cdot0425.$$

The resistances were therefore sensibly greater for the smaller disks than, according to the formula, they should have been. It will be seen presently that increasing the size of the chamber for a given disk increases its resistance. This is in accordance with the above deviation from the formula, because the smaller disks were in a chamber proportionately much larger than the largest disk. Hence, the increase of resistance in the smaller disks rather confirms than invalidates the formula.

For disks of different diameters in a chamber of constant size, the resistance varies as the $(n + 2\cdot82)$th power of the radius. The assumption on which the formula is based, involves that, for disks in chambers, bearing the same proportion to the disk, the resistance should vary as the $(n + 3)$th power of the radius. The difference is not great.

Influence of Temperature on the Resistance.—The four results with a bright brass disk, experiments 2, 22, 23, and 24, show that the friction diminishes with unexpected rapidity as the temperature increases. The diminution is sensible even for a few degrees difference of temperature, and hence it appears that a correction for temperature ought to be introduced in experiments on the flow of water in pipes and channels. The diminution between 41° and 130° Fahrenheit is about 18 per cent., or 1 per cent. for 5° increase of temperature.

The experiments were not numerous enough to determine exactly the law of variation of friction with temperature, and the apparatus was not adapted for securing a constant temperature during a prolonged experiment. The results agree fairly with the empirical formula

$$c_t = 0\cdot1328\,(1 + 0\cdot0021\,t),$$

where c_t is the value of c for a bright brass disk at the temperature $t°$.

In the experiments 1 to 17, the temperature varied in different instances from 53° to 62°. The factor

$$\frac{1 - 0\cdot0021 \times 60°}{1 - 0\cdot0021\,t}$$

has been used to reduce the values of c to a standard temperature

of 60°. The correction is in any case small, and does not affect the conclusions drawn from the results.

Influence of Roughness of Surface.—The results of the experiments are altogether in accord with those of Mr. Froude, as to the influence of the roughness of the surface. Even the numerical values of the frictional resistance obtained in these experiments differ very little from those obtained by him for long surfaces. Taking Mr. Froude's results for planks 50 feet long, and comparing them with those obtained in the present experiments, the resistances in lbs. per square foot at 10 feet per second are:—

Mr. Froude's Experiments.		Present Experiments.	
Tinfoil surface	0·232	Bright brass . .	0·202 to 0·229
Varnish	0·226	Varnish . . .	0·220 „ 0·233
Fine sand	0·337	Fine sand . .	0·339
Medium sand . . .	0·456	Very coarse sand.	0·587 „ 0·715

Power of the Velocity to which Resistance is proportional.—There is in this also a remarkable agreement between the present experiments and those of Mr. Froude. For the smoother surfaces, the resistance varies as the 1·85th power of the velocity. For the rougher surfaces as a power of the velocity ranging from 1·9 to 2·1. Mr. Froude's results are precisely the same.

Influence of the Size of Chamber on the Resistance.—In all these experiments without a single exception, the friction of the disk increased when the chamber in which it rotated was made larger. The Author is disposed to attribute this to the stilling of the eddies by the surface of the stationary chamber. The stilled water is fed back to the surface of the disk, and hence the friction depends not only on its own surface, but on that of the open chamber in which it rotates. The disks were rotated in chambers 3, 6, and 12 inches deep, and the surfaces of these chambers would be about 1,000, 1,200 and 1,600 square inches. In the larger chambers the kinetic energy of the water may be supposed to be more rapidly destroyed than in the smaller, in consequence of the larger area of stationary surface. The water being more rapidly stilled, and the stilled water fed back to the disk in greater quantity, the resistance of the disk is increased.

Effect of roughening the Surface of the Chamber.—In experiments 18 and 19 the upper and lower surfaces of the chamber were covered with coarse sand. Roughening the surface of the chamber materially increased the friction of the disk. This may be explained in precisely the same way as increase of friction due to increasing the size of the chamber.

The results of the most interesting experiments are plotted in Plate 3, Figs. 4, 5, 6, 7. The speed of the disk in revolutions per second is taken as abscissa, and the moment of frictional resistance in foot-lbs. as ordinate. The black dots give the actual experimental observations, and the curves drawn through them indicate the law of variation of resistance with speed. Fig. 4 shows the influence of variation of size of chamber, the disk being unchanged. Fig. 5 shows the influence of size of disk. Fig. 6 shows the influence of temperature, and Fig. 7 the effect of roughening the surface of the chamber.

The Paper is accompanied by several diagrams from which Plate 3 has been prepared.

APPENDIX.—RESULTS

Number of Experiment.	Nature of Disk and Surface.	Virtual Radius of Disk.	Thickness of Water Space on each side of Disk.	Temperature. Fahr.	Lowest Speed in Rotations per Second.
		Foot.	Inches.	°	
1	Clean polished brass	0·8488	1½	55·0	1·4257
2	„	„	3	53·0	1·4590
3	„	„	6	55·0	1·4150
4	Painted cast iron	„	1½	60·5	1·3801
5	„	„	3	61·0	1·3854
6	„	„	6	59·0	1·7876
7	Painted and varnished cast-iron disk	„	3	59·0	1·4493
8	„ „	„	6	63·0	1·4693
9	Tallowed brass	„	3	64·5	1·9585
10	„	„	3	67·0	1·9501
11	Cast iron	„	1½	55·0	1·4409
12	„	„	3	54·0	1·4192
13	„	„	6	55·0	1·4092
14	„ covered with fine sand .	„	3	56·5	1·5418
15	„ „ coarse sand	„	1½	62·5	1·1468
16	„ „ „	„	3	62·0	1·1136
17	„ „ „	„	6	62·0	1·3877
2	Clean polished brass	0·8488	3	53·0	1·4590
18	„	„	3	52·0	1·7851
16	Cast iron, covered with coarse sand	„	3	62·0	1·1136
19	„ „ „	„	8½	53·0	1·0869
2	Clean polished brass	0·8488	3	53·0	1·4590
20	„	0·6353	3	62·0	2·8169
21	„	0·4320	3	54·0	5·2300
22	Clean polished brass	0·8488	3	41·2	1·9350
2	„	„	3	53·0	1·4590
23	„	„	3	70·4	1·9841
24	„	„	3	130·5	2·8409
2	Clean polished brass	0·8488	3	53·0	1·4590
25	„	„	3	59·5	1·3839

Remarks.

2. Water a little coloured. 4. Water not quite clear. 5. Water a little coloured.

9. The surface of the tallow on the disk seemed to alter a little during immersion.

11, 12, 13. Cast iron a little rusty, having been used in preliminary experiments.

14. Disk coated with white lead and varnish, and covered with fine sand. Surface about as rough as ashlar stone.

15, 16, 17. Sand-coated cast-iron disk, the sand very coarse, and mixed with small gravel pebbles.

OF EXPERIMENTS.

Highest Speed in Rotations per Second.	Mean Value of n for each kind of Surface.	Mean Value of c.	Mean Value of c corrected to 60° Fahr.	Friction per Square Foot at 10 Feet per Second $=f\,10^n$.	——
5·8750	1·85	0·11027	0·10896	0·20187	
4·5010	,,	0·11491	0·11301	0·20937	
5·5310	,,	0·12562	0·12413	0·22998	
4·6860	1·86	0·11696	0·11709	0·21827	
5·3821	,,	0·12421	0·12451	0·23210	
5·1125	,,	0·13299	0·13267	0·24731	
4·8924	1·94	0·11061	0·11035	0·22002	
5·4705	,,	0·11607	0·11691	0·23310	
4·2373	2·06	0·09757	0·09863	0·21675	
5·1600	1·86	..	..	..	
5·0100	2·00	0·10293	0·10171	0·21292	
5·3248	,,	0·11015	0·10858	0·22730	
4·9900	,,	0·11762	0·11622	0·24329	
4·4563	2·05	0·15724	0·15574	0·33951	
3·3003	1·91	0·30047	0·30194	0·58749	
3·6049	,,	0·32613	0·32771	0·63763	
3·6550	,,	0·36589	0·36766	0·71535	
4·5010	1·85	0·11491	0·11301	0·20937	Chamber clean.
4·9751	1·95	0·12357	0·12122	0·24367	Chamber coated with rough sand.
3·6049	1·91	0·32613	0·32771	0·63763	Chamber clean.
2·7352	2·17	0·33817	0·33258	0·79867	Chamber covered with coarse sand.
4·5010	1·85	0·11491	0·11301	0·20937	Diameter varied.
7·5988	,,	0·03248	0·03263	..	
7·8490	,,	0·004873	0·00480	..	
5·6689	1·85	0·12153	..	0·22515	Temperature varied. Friction per square foot uncorrected for temperature.
4·5010	,,	0·11491	..	0·21289	
5·6306	,,	0·11127	..	0·20615	
5·1335	,,	0·100349	..	0·18591	
4·5010	1·85	0·11491	0·11301	0·20937	In water.
4·7081	1·93	0·119548	..	0·23644	In syrup, sp. gr. 1·061.

Remarks.

18, 19. The top and bottom of the chamber were coated with coarse sand, like the disk in experiments 15, 16, 17. In experiment 19 the water spaces were 3 inches on one side and 4 inches on the other side of the disk.

20. The disk was slightly greasy.

22. About two pailfuls of ice placed in water outside the copper chamber.

24. Water taken from an engine boiler. It was rather dirty from sediment produced by boiling.

25. Half a hundredweight of sugar dissolved in water in the cistern. This increased the density to 1·061.

(*Paper No. 2056.*)

"Method of Removing Rock under Water, as adopted in the Enlargement and Deepening of the Harbour and entrance Channel to the Welland Canal at Port Colborne."

By Charles James, Assoc. M. Inst. C.E.

The removal of large bodies of rock under water has for many years engaged the attention of some of the most eminent engineers on the Continent of America; but owing to the difficulties and cost attending such operations, until recently this class of work has seldom been undertaken.

Within the past twenty years considerable advances have been made in this branch of engineering, and at the present time extensive works are being carried out in improving the navigation of the Detroit and the St. Lawrence rivers, the method generally adopted for these works being similar to that introduced about sixteen years ago in the harbour works at Erie, Pennsylvania, and subsequently carried out with complete success in the enlargement and deepening of the harbour and entrance channel to the Welland Canal, at Port Colborne.

A contract for this work was awarded, in December 1871, by the Dominion Government, and included, amongst other matters, the removal of between 15,000 and 20,000 cubic yards of rock at the depth of from 10 to 15 feet under water. The contract price for rock-work was $6.50 per cubic yard; but this contract was abandoned after several months spent in ineffectual attempts to displace the rock with "Giant Powder."

In 1875 tenders were again called for, the depth of water from the harbour outwards to be increased from its then average depth of 12 feet to a minimum depth of 17 feet; this involved the removal of several reefs of blue limestone rock thickly studded with flint. Many tenders were received, ranging from $9.90 to $40 per cubic yard for rock under water. The contract was awarded to Mr. Charles F. Dunbar, of Erie, Pennsylvania, the contract price being $9.90 per cubic yard.

From former experiments made in this class of rock, it was

found that a more powerful explosive than any heretofore used was requisite, and that to make the charge thoroughly effective the explosive must be confined to the smallest possible space at the bottom of the hole, and be placed at such a depth as would cause the entire force of the charge to be exerted upwards on the mass to be removed.

It was therefore determined to make a trial with pure nitroglycerine, and to place the charge from 12 to 15 inches below the required bottom.

The first experiments, though not altogether successful, were highly encouraging, and in the course of a few weeks a method of submarine blasting was perfected that commends itself to the notice of engineers engaged in similar undertakings.

A rectangular flat-bottomed scow 30 by 50 feet, drawing about 2 feet of water, was used to carry the plant. This comprised a boiler and engine, with two 8-inch cylinders, for hoisting anchors; two "Ingersoll" drills, having cylinders 5 inches in diameter and a length of stroke of 8 inches, averaging about four hundred strokes per minute, and a blacksmith's shop for repairing and making drills. The size of drill varied between 1¾ inch and 2¼ inches in diameter, with four cutting edges of steel, highly tempered, radiating at right angles from the centre. Each drill worked in an independent sliding frame, on a tramway of strap-iron laid on the deck, and so placed as to allow sufficient room for the free working of the drill alongside the scow. A hose connected with the boiler supplied the motive power, the cut-off being placed within easy reach of the man attending the drill. The scow was kept in position by four drop-anchors of heavy oak timber, two at each end, similar to those used on dredgers, and secured in a strong frame raised about 9 feet above the deck.

The hands employed were: a foreman, blacksmith and assistant, four men attending drills, and one blaster and assistant.

Holes were drilled in the rock 5 feet apart, generally about 30 inches below the required depth, a cast-iron shell weighing about 100 lbs. being used to steady the lower end of the drill when entering the rock. This shell was about a foot in height, 15 inches in diameter at the base, standing on three pivots or legs, about 3 inches long, convex on the top, through the centre of which a hole passed vertically admitting of the free working of the drill; ropes were attached leading to the scow, by which it was lowered and raised.

When the drilling of each hole was completed, the sediment was removed by forcing water through a tube reaching from the deck

to the bottom of the hole, a "Blake" pump and hose being employed for that purpose.

The cartridge, a tin canister $\frac{7}{8}$ inch in diameter, 15 inches long, was filled with explosive to within about an inch of the top, the exploder (fulminate of mercury) enclosed in a copper capsule, into which the insulated copper wires were passed, and to which they were secured by the maker, was inserted in the cartridge. This was sealed and attached to similar wires of sufficient length to reach the bottom of the hole and connect with the electric battery on the scow. The cartridge was next placed in a tin tube $1\frac{1}{2}$ inch in diameter about 20 feet long, through one end of which a slit in the side extending the full length of the cartridge admitted the easy passage of the insulated wires; the latter were drawn tightly, passing along outside the tube, which was carefully lowered to the bottom of the hole. A wooden rod was gently pushed by hand through the tube, to keep the cartridge down, and the tube withdrawn.

A quantity of explosive, varying from 2 lbs. to 5 lbs., in proportion to the depth of rock, was then poured through a funnel-shaped copper tube into the hole, and afterwards a few gallons of hot water to remove any particles of explosive adhering to the sides of the tube, the wires were finally connected with the battery and the charge exploded.

The practice generally followed was to charge and explode each hole so soon as the drill was removed, and before commencing to drill another hole, as any disturbance of the wires after loading tended to injure the circuit. The explosive, before being used, was congealed by packing in ice and sawdust; the temperature was raised before loading to 60° Fahrenheit by immersing the can in hot water. The loading of each hole occupied only a few minutes, but had to be conducted with the greatest care, the following rules being strictly observed:—

1. That the hole was drilled to a sufficient depth below the required bottom.
2. That the cartridge was placed at the bottom of the hole.
3. That in withdrawing or inserting the tubes and completing the loading no obstruction was allowed to enter the hole.

The necessity for such precautions is obvious, from the fact that pure nitro-glycerine can only be exploded by concussion, hence the necessity for placing the cartridge containing the exploder in such a position as would ensure its contact with the liquid explosive that completed the charge, and which, owing to its specific gravity, would speedily fill every space around the cartridge, and

penetrate every fissure of the rock. The electric spark transmitted through the exploder caused almost instantaneous concussion, and exploded the whole charge, yet to a person standing on the scow, or in close proximity to the works, two distinct explosions in rapid succession could always be felt and heard.

Several experiments were made to ascertain at what temperature the explosive became dangerous. At 32° Fahrenheit it was found to be non-explosive, at 40° it required careful handling, and at 60° became highly sensitive, needing the exercise of the greatest vigilance. A single accident occurred during the four years over which this work extended, at a considerable distance from the works.

After blasting, the rock was easily removed by the dredge; a few instances occurred where it was necessary to return with the drill, but only at the commencement of the work. Subsequently the bottom was carefully dragged, a derrick scow and diver being used to pick up any blocks of stone that had escaped the dredge.

Finally soundings were taken at intervals of 5 feet; the result showed an average depth of 17½ feet, with a minimum depth of 17 feet, and a total of 34,600 cubic yards of rock removed.

The consumption of explosives was 45,600 lbs. at an average cost of $1 per lb.; the area of rock surface removed was 303,000 square feet, with an average depth at the line of 17 feet water of 2·58 feet. Assuming each hole to have been drilled 2½ feet below the required bottom, and the area of rock surface to have been 25 feet to each hole, the annexed Table is submitted as a close approximation of the work performed.

APPENDIX.

Area of rock surface	303,000 square feet.
„ to each hole	25 „
Number of holes drilled	12,120
Average depth per hole	5·08 lineal feet.
Total depth drilled	61,569 „
Average charge per hole	3·76 lbs.
„ per cubic yard . .	1·32 „
Rock removed	34,600 cubic yards.
Quantity of explosive used	45,600 lbs.
Average depth of water obtained . .	17½ feet.

(*Paper No. 2073.*)

"Guns Considered as Thermodynamic Machines."

By JAMES ATKINSON LONGRIDGE, M. Inst. C.E.

IN the following Paper the Author pursues to a great extent the lines indicated by Count de St. Robert in his "Principes de Thermodynamique," Turin, 1870; and from the principles therein laid down, deduces formulas applicable to rifled guns, for determining the initial velocity of the projectile, and the velocity of recoil of the gun and carriage.

The determination of these velocities by the method usually adopted in this country is purely empirical, and it therefore appears desirable to attempt, at any rate, a more scientific method. This is the more desirable, on account of the mystification existing on the subject of so-called slow-burning powder and large charges in chambered guns. It is almost the same as if manufacturers of steam-engines were to give their chief attention to the way in which steam is generated, to the exclusion in a great measure of the consideration of how it is used.

Now a gun is just as much a machine as is a steam-engine, and in both mechanical force is obtained from a gaseous fluid. In the gun the fluid is the powder-gas which passes through a cycle, of which the initial state is the ignition of the powder, and the final state that when the projectile leaves the gun; consequently the following equation must result—

$$J \Delta H = J \Delta Q + \Delta I + \Delta W + \tfrac{1}{2} \Delta V \quad . \quad . \quad . \quad . \quad (1)$$

in which—

J is Joule's coefficient = 772 foot-lbs. to 1 unit of heat.

(1) Δ H is the heat extracted from the products of combustion in passing from the initial to the final state, *i.e.*, from the ignition of the powder to the time when the projectile leaves the muzzle.

(2) Δ Q is the quantity of heat passing from the gases into the body of the gun, and which goes to heat the gun.

(3) Δ I is the increment of internal work in the gases during the same time.

(4) Δ W is the external work done, and includes the work done in overcoming the statical resistance of the air to the projectile, but does not include the increased resistance of the air due to velocity. It also includes the work done in rotating the projectile, the friction of the same, and gas-check, the friction of the gases in the chase, and the work done in stretching the material of the gun.

(5) Δ V is the sum of the *vis viva* acquired by the system, and includes $\int R\, d\, s$, or the resistance of the air due to the velocity of the projectile.

Determination of the above.

(1) Δ H.

The powder is transformed into two portions, one of which is gaseous, the other non-gaseous, and according to Noble and Abel's researches,[1] these are by weight:—

Gaseous products . .	43 per cent.;	specific heat, 0·186
Non-gaseous products	57 ,,	,, 0·450

Consequently, if w be the weight of the charge, t_o and t the initial and final temperatures,

$$\Delta H = \{0{\cdot}57\, w \times 0{\cdot}45 + 0{\cdot}43\, w \times 0{\cdot}186\}\ (t_o - t) = 0{\cdot}3385\, w\, (t_o - t) \quad . \quad . \quad . \quad (2)$$

t_o is given by Noble and Abel at 2,000° to 2,100° C. or 2,274° to 2,374° C. absolute. In future calculations it is taken at 2,342° C. or 4,215° Fahr. absolute.

t is obtained from the equation (Noble and Abel)—

$$t = t_o\left(\frac{v_o\,(1 - a)}{v - a\, v_o}\right)^{\frac{C\mu - C v}{C v - a v_o}} = t_o\left(\frac{0{\cdot}43}{\frac{v}{v_o} - 0{\cdot}57}\right)^{0{\cdot}074} \quad . \quad . \quad . \quad (3)$$

v_o and v being the volumes before and after expansion.

(2) Δ Q. Heat imparted to the walls of the gun.

There is a good deal of uncertainty about this. The Author investigated it at some length in "A Treatise on the Application of Wire to the Construction of Ordnance" (Spon, London, 1884), and at page 144 of that work gave a diagram, which probably represents approximately the heat imparted to each square foot

[1] Philosophical Transactions of the Royal Society of London. For the year 1880, p. 203.

of surface of the interior of the gun. The application of this diagram will be found further on.

(3) Δ I. Internal work in gases.

The internal work in a perfect gas = o, and as powder gases approach very nearly to the condition of a perfect gas, we may take

$$\Delta 1 = 0.$$

(4) Δ W.

This comprises the following items :—

(*a*) *Resistance of Air* $= p.A.l$ . . . . (4)

p = atmospheric pressure.
A = area of bore. l = length of travel of shot.

(*b*) *Work done in Rotation* $= \dfrac{W}{2g} \cdot \left(\dfrac{0 \cdot 707\, \pi\, u}{m}\right)^2$ . . . . (5)

W = weight of shot. m = number of calibres to 1 turn of shot.
u = muzzle velocity.

(*c*) *Friction of Shot.*—Let the pitch of rifling be 1 in n, and let P be the pressure on the base of the shot, then

$$\text{Force to give rotation} = \frac{\pi P}{2n},$$

and if p be the powder pressure at any part x of the chase

$$P_1 = p\, \pi\, \rho^2. \quad \therefore \text{ force at } x = \frac{\pi^2 \rho^2}{2n} \cdot p.$$

Now if P_1 be the initial pressure $p = P_1 \left(\dfrac{v_0\,(0 \cdot 1 - a)}{v_1 - a\, v_0}\right)^{1 \cdot 237}$

$$= P_1 \left(\frac{0 \cdot 43}{\frac{v_1}{v_0} - 0 \cdot 57}\right)^{1 \cdot 237}$$

where v_1 is the volume of gases at x,

therefore $\qquad$ Force at $x = \dfrac{\pi^2 \rho^2}{2n} \cdot P_1 \left(\dfrac{0 \cdot 43}{\frac{v_1}{v_0} - 0 \cdot 57}\right)^{1 \cdot 237}$,

and if the friction be taken at $\dfrac{1}{m}$th, and if P_1 be in tons per square inch, the total work done is found.

$$\frac{1}{m} \cdot \frac{\pi^2 \rho^2}{2n} 2240 \, P_1 \int^{l} \left(\frac{0 \cdot 43}{\frac{v_1}{v_0} - 0 \cdot 57} \right)^{1 \cdot 237} d\,x \;.\;.\;.\;.\;.\;.\;. \quad (6)$$

and writing $\frac{v_1}{v_0}$ in terms of x, and integrating, the work done in foot-lbs. is ascertained.

(*d*) *Work done in overcoming Friction of Gas-check and Shot.*—As it is the gas-check in the Woolwich system that gives the rotation, this friction is included in the preceding items. No doubt an extra force is required at first to force it into the grooves, but as this is not continuous, and amounts probably to only a few lbs. per square inch on the area of the base of the shot at its first starting, it may be neglected.

(*e*) *Work done in overcoming Friction of the Gases in the bore.*—There must of course be some uncertainty about this, as so little is known of the laws of gaseous friction at high pressures; but as an approximation it may be assumed with Rankine[1] that the resistance $= f \rho \, S \, \frac{V^2}{2g}$.

when $f = 0 \cdot 006$.
$\rho =$ weight in lbs. of cubic foot of gas.
$S =$ surface of contact in square feet.
$V =$ velocity in feet per second.

Now at the breech $V = o$, and at the muzzle it is the velocity of the shot. The weight of a cubic foot of the gas at the beginning of motion $= \dfrac{w}{\dfrac{\pi \rho_1^2 \times l}{1{,}728}} = \dfrac{1{,}728\, w}{\pi \rho_1^2 \, l}$ when l and ρ_1 are the length and radius of the powder chamber.

Therefore at any other point x the weight of a cubic foot $= \dfrac{1{,}728}{\pi \rho_1^2 l} \cdot \dfrac{l_1}{x + l_1}$ where l_1 is the equivalent length of the powder chamber, or the length which it would have, if of the same diameter as the bore. Now if it be assumed that the velocity of the gas increases uniformly from the breech to the muzzle, then

Velocity at $x = V \dfrac{x}{L}$, L being the travel of the shot and V the muzzle velocity.

[1] "A Manual of Applied Mechanics." By William John Macquorn Rankine, 1858, p. 584.

Consequently

$$\text{Resistance} = 0\cdot006 \times \frac{1{,}728\, w}{\pi\, \rho_1{}^2\, l} \cdot \frac{l_1}{x + l_1} \cdot \text{S} \cdot \frac{\text{V}^2 x^2}{2\, g\, \text{L}^2},$$

and as this acts through $d\,x$—

$$\text{Work done} = \frac{0\cdot006 \times 1{,}728\, w \times l_1\, \text{S} \times \text{V}^2}{\pi\, \rho_1{}^2\, l\, 2g} \cdot \int_0^{\text{L}} \frac{x\, d\, x}{\text{L}^2} \quad . \quad (7)$$

which being integrated gives the work done in foot-lbs.

(*f*) *Work done in Stretching the Gun circumferentially.*—The powder-pressure inside the gun acts upon any elementary shell by extending it circumferentially and compressing it radially.

Let there be such a shell at radius y, and let its thickness and breadth be $d\,y$ and β respectively.

Let t_y be the tension at y per square inch of section.
f_y the radial compressive force in ditto.
x the extension under t_y.
l the length $= 2\,\pi\,y$.
E the modulus of elasticity.

Then $x = l\,\frac{t_y}{\text{E}}$.

Now for any intermediate extension z, let ϕ be the force exerted, then $z = l\,\frac{\phi}{\text{E}}$, or $\phi = \frac{\text{E}}{l}\,z$, and work done through $d\,z = \frac{\text{E}}{l}\,z\,d\,z \times \beta\,d\,y$, because $\beta\,d\,y$ is the area of section.

Integrating in respect of z, when z becomes $= x = l\,\frac{t_y}{\text{E}}$, the work done $= \frac{l\,\beta\,t_y{}^2}{2\,\text{E}} \cdot d\,y$, and replacing l by $2\,\pi\,y$, the work done $= \frac{\pi\,\beta\,t_y{}^2\,y\,d\,y}{\text{E}}$.

But t_y is a function of y, and if f_1 be the internal powder-pressure, ρ the internal radius, R the external radius, and $m = \frac{\text{R}}{\rho}$.

$$t_y = \frac{f_1}{m^2 - 1} \cdot \frac{\text{R}^2 + y^2}{y^2},$$

substituting which in the above—

$$\text{Work done} = \frac{\pi\,\beta}{\text{E}} \cdot \frac{f_1{}^2}{(m^2 - 1)^2} \cdot \int \left(\frac{\text{R}^2 + y^2}{y^2}\right)^2 y\,d\,y,$$

which by integration gives—

$$\text{Work done} = \frac{\pi\beta}{\mathrm{E}} \cdot \frac{f_1^2}{(m^2-1)^2}\left\{\frac{m^2-1}{2}\mathrm{R}^2 + 2\,\mathrm{R}^2\log m + \frac{\mathrm{R}^2+y^2}{2}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Proceeding in like manner for compression—

Work done

$$= \frac{\pi\beta}{\mathrm{E}} \cdot \frac{f_1^2}{(m^2-1)^2}\left\{\frac{m^2-1}{2}\mathrm{R}^2 + 2\,\mathrm{R}^2\log\frac{1}{m} + \frac{\mathrm{R}^2-y^2}{2}\right\} \quad (9)$$

therefore adding—

$$\text{Total work done} = \frac{\pi\beta}{\mathrm{E}} \cdot f_1^2\,\frac{m^2+1}{m^2-1} \cdot \rho^2 \quad . \quad . \quad . \quad . \quad . \quad (10$$

and if the units be tons and inches, and $\beta = 1$, this gives inch-tons per lineal inch of bore, or foot-tons per lineal foot of bore; and since the surface of 1 lineal foot of bore $= \frac{2\,\pi\,\rho \times 12}{144} = \frac{\pi\,\rho}{6}$, finally

$$\textit{Work done per square foot of surface} = \frac{6\,f_1^2\,\rho}{\mathrm{E}} \cdot \frac{m^2+1}{m^2-1}$$
$$\text{in the chamber} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

To find the work done in the rest of the chase.

Let p be the powder-pressure at any part x,

then $$p = \mathrm{P}_1\left(\frac{v_0\,(1-a)}{v_1 - a\,v_0}\right)^{1\cdot237},$$

or, as was shown before,

$$= \mathrm{P}_1\left(\frac{0\cdot43}{\frac{v_1}{v_0} - 0\cdot57}\right)^{1\cdot237},$$

which is the value of f_1 to be used in the above equation; therefore the work done on unit of length of bore

$$= \frac{\pi}{\mathrm{E}} \cdot \frac{m^2+1}{m^2-1} \cdot \rho^2 \cdot \mathrm{P}_1^2\left(\frac{0\cdot43}{\frac{v_1}{v_0} - 0\cdot57}\right)^{2\cdot474},$$

and work done in $d\,x$

$$= \frac{\pi}{\mathrm{E}} \cdot \left(\frac{m^2+1}{m^2-1}\right) \cdot \rho^2 \cdot \mathrm{P}_1^2\left(\frac{0\cdot43}{\frac{v_1}{v_0} - 0\cdot57}\right)^{2\cdot474} d\,x \quad . \quad (12)$$

and expressing $\frac{v_1}{v_0}$ in terms of x, and integrating, taking $x = L$ the length of the chase, the total work done in foot-lbs. is ascertained.

There now only remains to determine the work done in extending the gun between the breech and the trunnions. It will be assumed that the strain is uniformly distributed over the cross-section of the gun.

Then the strain per square inch is $\frac{P_1 \rho^2 \pi}{(R^2 - \rho^2)\pi} = \frac{P_1}{m^2 - 1}$ which call f, thus if l be the length from breech to trunnion, total extension $= f\frac{l}{E}$.

Now for any intermediate extension y, the force $= E\frac{y}{l}$, and work done in $d\,y = E\left(\frac{y\,d\,y}{l}\right)$. Integrating, since $y = f\frac{l}{E}$, work done $= \frac{f^2\,l}{2\,E}$ per square inch of surface, and since the area is $2\,\pi\,(R^2 - \rho^2)$, and $f = \frac{P_1}{m^2 - 1}$.

Total work $$\frac{\pi\,(R^2 - \rho^2)\,l \cdot P_1^2}{E\,(m^2 - 1)^2} \quad \ldots\ldots\ (13)$$

(5) Δ V.

This is made up of the following items:—

(*a*) *Vis viva* of projection $= \frac{W}{g} \cdot u^2$ . . . . . . (14)

when W = weight and u = muzzle velocity of projectile.

(*b*) *Vis viva* of gun and carriage $= \frac{W_1}{g}\,u_1^2$ . . . (15)

when W_1 is the weight of gun and recoiling part of carriage.

(*c*) *Vis viva* of the gases $= \int u_{\prime\prime}^2\,d\,\mu$, when μ is the mass or $\frac{w}{g}$, w being the weight of the charge, and $u_{\prime\prime}$ the varying velocity of the gas at varying distances from the breech at the time the shot reaches the muzzle.

This integral must be taken for the whole mass of the products of combustion from the breech to the muzzle. It depends on the state of the particles and their respective velocities at the time the shot leaves the gun.

Some uncertainty as regards this is unavoidable; but probably it will not lead to any important error if it be assumed, first, that the density of the products of combustion at any moment is uniform throughout; second, that these velocities increase uniformly from the breech to the muzzle; and lastly, that the layers or transverse slices of the products in contact with the breech and the projectile have respectively the velocities of the gun and of the projectile, viz., u_1 and u. This being so, there must be some point where the gases are at rest, and this point divides the whole length in the ratio of u and u_1.

Let l be the length of the chase, then the point of rest will be

$$\frac{u_1}{u + u_1} \cdot l \text{ from the breech,}$$

$$\frac{u}{u + u_1} \cdot l \text{ from the muzzle,}$$

and for any intermediate point x from the point of rest, on the muzzle side, the velocity will be

$$u \frac{x}{\frac{u\,l}{u + u_1}} = \frac{u + u_1}{l} \cdot x$$

also at y from point of rest on breech side

$$\text{velocity} \qquad = \frac{u + u_1}{l} \cdot y.$$

Now let δ = density of products of combustion.
A = area of the bore.

Since the moments are equal on each side of the point of rest,

$$\text{moment on the muzzle side} = \frac{\delta\,A}{g} \cdot \frac{u + u_1}{l} \int_0^{\frac{u\,l}{u + u_1}} x\,d\,x$$

$$= \frac{\delta\,A\,l}{2\,g} \cdot \frac{u^2}{u + u_1}.$$

and on the other side the moment is

$$\frac{\delta\,A\,l}{2\,g} \cdot \frac{u_1^2}{u + u_1},$$

and as these are in opposite directions their algebraic sum is

$$\frac{\delta\,A\,l}{2\,g} \cdot \frac{u^2 - u_1^2}{u + u_1} = \frac{\delta\,A\,l}{2\,g}(u - u_1) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

which is the total momentum.

Now $\delta A l$ represents the total weight of the products of combustion $= w$

$$\therefore \int u_{\prime\prime}\, d\mu = \frac{w}{2g}(u - u_1),$$

which is the total momentum of the products of combustion.

For the *vis viva*, there is for those moving in the direction of the projectile

$$\frac{\delta A}{g}\left(\frac{u + u_1}{l}\right)^2 \int_0^{\frac{u l}{u + u_1}} x^2\, dx,$$

and for those moving in the opposite direction

$$\frac{\delta A}{g}\left(\frac{u + u_1}{l}\right)^2 \int_0^{\frac{u l}{u + u_1}} y^2\, dy$$

the integrals of which are

$$\frac{\delta A l}{3g} \cdot \frac{u^3}{u + u_1} \text{ and } \frac{\delta A l}{3g} \cdot \frac{u_1^3}{u + u_1},$$

therefore the total momentum is

$$\frac{\delta A l}{3g} \cdot \frac{u^3 + u_1^3}{u + u_1} = \frac{w}{3g} \cdot (u^2 + u_1^2 - u\, u_1),$$

which is the value of $\int u_{\prime\prime}^2\, \delta\mu$ . . . . (17)

It remains to determine the value of $\int R\, ds$, or the work done in overcoming the resistance of the air due to the velocity.

Taking the resistance as proportionate to the cube of the velocity and $= a\, u^3$. a is a coefficient depending on the diameter of the projectile and the form of the head.[1]

Then $R = a\, u^3$.

To determine v in terms of the space.

No exact function determining this has yet been obtained, but from an examination of the velocity curves given by the Committee on Explosives, Preliminary Report, 1870, it appears that the relation is very nearly $u = 744\, S^{\frac{1}{3}}$ for pebble powder in an 8-inch gun with a projectile of 180 lbs.

therefore $$R = a \cdot (744)^3\, S,$$

and $$\int R\, ds = (744)^3\, a \int_0^L s\, ds$$

$$= \frac{(744)^3\, a\, L^2}{2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (18)$$

[1] "Reports on Experiments made with the Bashforth Chronograph." Part II. 1878–79. Table II., Appendix to Report VIII.

To determine u and u_1 there is the further relation from the equality of moments

$$m_1 u_1 = m u + \int u_{,,} \delta \mu,$$

or

$$\frac{W_1}{g} u_1 = \frac{W}{g} u + \frac{w}{2g}(u - u_1),$$

or

$$W_1 u_1 = W u + \frac{w}{2g}(u - u_1) \quad . \quad . \quad . \quad . \quad (19)$$

from which u_1 is obtained in terms of u, and substituting this in the former equation, u the muzzle velocity is found, and then from the last equation u_1 the velocity of recoil.

To proceed to an application of the preceding formula.
Take the 10 inches B.L. Woolwich gun of 27 tons.

Weight of projectile . . .	500 lbs. = W.
„ of charge	300 lbs. = w.
Length of chamber. . . .	54 inches.
Diameter of „	14 „
Length beyond chamber . .	27·0 feet.
Diameter „ „ . .	10·0 inches.
Capacity of chamber . . .	8,316 cubic inches = v_o.
Total capacity of gun . . .	29,522 „ „ = v.

Therefore $\frac{v}{v_o} = 3 \cdot 55$.

(1) Determinations of J Δ H.
As shown before, this is

$$= 0 \cdot 3585\, w\, (t_o - t),$$

now $$w = 300 \text{ lbs. } t_o = 4{,}215^\circ \text{ Fahrenheit (absolute)},$$

and $$t = t_o \left(\frac{0 \cdot 43}{\frac{v}{v_o} - 0 \cdot 57} \right)^{0 \cdot 074}.$$

Now $\frac{v}{v_o} = 3 \cdot 55 \therefore t = 4{,}215 \times \left(\frac{0 \cdot 43}{2 \cdot 98}\right)^{0 \cdot 074} = 3{,}652^\circ.$

Consequently fall of temperature = 4,215 − 3,652 = 563°,

and $$J \Delta H = \frac{772 \times 300 \times 0 \cdot 3385 \times 563}{2{,}240} = 19{,}513 \text{ foot-tons.}$$

(2) Numerical determination of J Δ Q.
Referring to the diagram, p. 144, "A Treatise on the Application

of Wire to the Construction of Ordnance," it will be found that the heat imparted to the body of the gun is as follows:—

Powder-chamber per square foot of surface .	168 units.
In first expansion average " " .	98 "
In second do. " " " .	53 "
In 1st half of third do. " " .	40 "

Therefore taking the surfaces—

$$\text{Powder-chamber } \frac{54 \times 44}{144} = 16\tfrac{1}{2} \text{ sq. ft.} \times 168 = 2{,}772 \text{ units.}$$

$$\text{First expansion } \frac{107 \times 31 \cdot 41}{144} = 23\tfrac{1}{3} \text{ "} \times 98 = 2{,}307 \text{ "}$$

$$\text{Second " } \frac{107 \times 31 \cdot 41}{144} = 23\tfrac{1}{3} \text{ "} \times 53 = 1{,}237 \text{ "}$$

$$\text{Remainder } \frac{56 \times 31 \cdot 41}{144} = 11 \text{ "} \times 40 = 440 \text{ "}$$

$$\text{Total . . . . } 6{,}756 \text{ "}$$

$$\text{Therefore } J \Delta Q = \frac{6{,}756 \times 772}{2{,}240} = 1{,}850 \text{ foot-tons.}$$

(3) $\Delta I = o$.

(4) Determinations of Δ W.

(*a*) Resistance of air. $p \Delta l$

$$= \frac{14 \cdot 75 + 78 \cdot 54 + 25 \cdot 5}{2{,}240} = 13 \cdot 89 \text{ foot-tons.}$$

(*b*) For rotation

$$\text{Work done} = \frac{\frac{W}{2g}\left\{\frac{0 \cdot 707\, \pi\, u}{m}\right\}^2}{2{,}240},$$

Now W = 500

m = pitch of rifling or number of calibres for 1 turn of shot, and let this be 30.

Therefore

$$\text{Work done} = \frac{500 + 0 \cdot 00548}{64 \cdot 4 + 2{,}240} u^2 = 0 \cdot 00002\, u^2.$$

(*c*) For friction of gas ring, and shot. The expression for this is

$$\frac{\frac{1}{m} \cdot \frac{\pi^2 \rho^2}{2\,n} + 2{,}240\ P_1 \int_o^l \left(\frac{0 \cdot 43}{\frac{v_1}{v_0} - 0 \cdot 57}\right)^{1 \cdot 237} d\,x}{2{,}240}$$

$\frac{1}{m}$ the coefficient of friction may be taken $= \frac{1}{5}$

$$n = 30;\ \rho = 5;\ P_1 = 18;\ l = 25 \cdot 5.$$

To determine $\frac{v_1}{v_o}$ there is $v_o = 8{,}316$ cubic inches,

and $\qquad v_1 = 78 \cdot 54\, x + 8{,}316.$

$$\therefore \frac{v_1}{v_o} = \frac{78 \cdot 54\, x + 8{,}316}{8{,}316} = 0 \cdot 00944\, x + 1.$$

$$\therefore \int_o^l \left(\frac{0 \cdot 43}{\frac{v_1}{v_o} - \cdot 57}\right)^{1 \cdot 237} = \int_o^l \left(\frac{0 \cdot 43}{0 \cdot 00944\, x + 0 \cdot 43}\right)^{1 \cdot 237}$$

and the expression becomes

$$\frac{1}{5} \cdot \left(\frac{15 \cdot 7075}{60}\right)^2 \times 18 \int_o^l \left(\frac{0 \cdot 43}{0 \cdot 00944\, x + 0 \cdot 43}\right)^{1 \cdot 237} d\,x$$

$$= 14 \cdot 93 \int_o^l \frac{d\,x}{(0 \cdot 0219\, x + 1)^{1 \cdot 237}}.$$

Now the integral of $\frac{d\,x}{(a + b\,x)^n} = -\frac{1}{(n-1)\,b\,(a+b\,x)^{n-1}}.$

Therefore the above becomes

$$\int - \frac{1}{0 \cdot 237 \times 0 \cdot 0219\,(0 \cdot 0219\, x + 1)^{0 \cdot 237}},$$

and this taken between $x = l$ and $x = o$ gives

$$-\frac{1}{0 \cdot 0219 \times 0 \cdot 237 \times (0 \cdot 0219\, l + 1)^{0 \cdot 237}} - -\frac{1}{0 \cdot 237 \times 0 \cdot 0219}$$

$$= 192 \cdot 6 - \frac{192 \cdot 6}{(0 \cdot 0219\, l + 1)^{0 \cdot 237}}$$

and making $\qquad l = 25 \cdot 5$

$$= 192 \cdot 68 - \frac{192 \cdot 68}{1 \cdot 1109} = 192 \cdot 68 - 173 \cdot 46 = 19 \cdot 22.$$

$\therefore$ Work done $= 14 \cdot 93 \times 19 \cdot 22 = 286 \cdot 9$ foot-tons.

(*d*) Friction of the gases. The weight of a cubic foot of gas at the beginning is

$$\frac{1{,}728\, w}{\pi \rho^2 l} = \frac{1{,}728 \times 300}{3 \cdot 1416 \times 25 \times 54} = \frac{518{,}400}{8{,}316} = 62 \cdot 34 \text{ lbs.}$$

and since l_1 the equivalent length of the chamber $= \frac{8{,}316}{78 \cdot 52} =$ 107 inch $= 8 \cdot 93$ feet. Therefore weight of a cubic foot at $x = 62 \cdot 34 \times \frac{8 \cdot 93}{x + 8 \cdot 93}$, and if it be assumed that the velocity of the gas increases uniformly from the chamber to the muzzle, the velocity at $x = u \frac{x}{\text{L}}$, u being the muzzle velocity, and L the travel of the shot $= 25 \cdot 5$ feet. Hence the resistance per unit of surface at x

$$= 0 \cdot 006 \times 62 \cdot 34 \times \frac{8 \cdot 93}{x + 8 \cdot 93} \times \text{S} \cdot \frac{u^2 x^2}{2 g \text{L}^2}.$$

Now S is the unit of surface in feet

$$\therefore \text{S} = \frac{\pi d}{12}.$$

Therefore the work due to the resistance through $d x$

$$= 0 \cdot 006 \times 62 \cdot 34 \times \frac{8 \cdot 93}{x + 8 \cdot 93} \times \frac{\pi d}{12} \cdot \frac{u^2}{2 g \text{L}^2} \cdot x^2 d x$$

$$= 0 \cdot 000209\, u^2 \int_0^{\text{L}} \frac{x^2}{x + 9 \cdot 83} d x;$$

but $\qquad \int \frac{x^2 d x}{a + b x} = \frac{x^2}{2 b} - \frac{a x}{b^2} + \frac{a^2}{b^3} \log (a + b x),$

and here $\qquad a = 9 \cdot 83 \quad b = 1,$

therefore the integral is

$$\frac{x^2}{2} - 9 \cdot 83\, x + 9 \cdot 83^2 \log (9 \cdot 83 + x)$$

when $x = \mathrm{L}$ this becomes

$$\frac{\mathrm{L}^2}{2} - 9{\cdot}83\ \mathrm{L} + 9{\cdot}83^2 \log\,(9{\cdot}83 + \mathrm{L}),$$

and when $x = o$ it becomes $9{\cdot}83^2 \log 9{\cdot}83$.

Therefore the integral between these limits is

$$\frac{\mathrm{L}^2}{2} - 9{\cdot}83\ \mathrm{L} + 9{\cdot}83^2\,(\log\,(9{\cdot}83 + 1) - \log 9{\cdot}83)$$

$$= \frac{\mathrm{L}^2}{2} - 9{\cdot}83\ \mathrm{L} + 9{\cdot}83^2 \left\{\log.\ \frac{9{\cdot}83 + \mathrm{L}}{9{\cdot}83}\right\}$$

and since $\mathrm{L} = 25{\cdot}5$.

This becomes $325{\cdot}12 - 151{\cdot}17 + 96{\cdot}63\ \{\log 3{\cdot}594\}$

$$= 173{\cdot}95 + 96{\cdot}63 \times 1{\cdot}2693$$

$$= 173{\cdot}95 + 122{\cdot}65 = 296{\cdot}60.$$

Therefore the work done $= 0{\cdot}000209 \times 296{\cdot}6\ u^2$ in foot-lbs.

$$= \frac{0{\cdot}000209 + 296{\cdot}6}{2{,}240}\,u^2 \text{ in foot-tons.}$$

$$= 0{\cdot}00002765\ u^2 \text{ in foot-tons.}$$

(*e*) Work done in stretching guns.

In the chamber it is per square foot of surface

$$\frac{6\,f_1^{\,2}\,\rho}{\mathrm{E}} \cdot \frac{m^2 + 1}{m^2 - 1}$$

$$f_1 = 18 \text{ tons} \qquad \rho = 5 \text{ inches,}$$

and if $\mathrm{R} = 20$ inches

$$\rho = 7 \text{ in the chamber}$$

$$\frac{m^2 + 1}{m^2 - 1} = \frac{\mathrm{R}^2 + \rho^2}{\mathrm{R}^2 - \rho^2} = \frac{449}{351} = 1{\cdot}28,$$

$$\mathrm{E} = 13{,}000 \text{ tons,}$$

and the surface of the chamber $= \dfrac{54 \times 43{\cdot}98}{144} = 16{\cdot}5$ square feet.

Therefore the work done

$$= \frac{6 \times 18^2 \times 5 \times 1{\cdot}28 \times 16{\cdot}5}{13{,}000} = 15{\cdot}8 \text{ foot-tons.}$$

For the rest of the chase.

To be accurate, the length of the chase should be divided into sections, but as the only term which is affected by the difference in thickness is $\frac{m^2+1}{m^2-1}$, and as this is a comparatively small factor and does not vary much, it will be sufficient to take a mean value of the outer radius, which, accordingly, will be taken at 10 inches, and $\rho = 5$,

therefore $$\frac{m^2+1}{m^2-1} = \frac{R^2+\rho^2}{R^2-\rho^2} = \frac{125^3}{75} = 1 \cdot 333.$$

Now the expression for the work done is

$$\frac{\pi}{E} \cdot \frac{m^2+1}{m^2-1} \rho^2 P_1^2 \int^{c} \left(\frac{0 \cdot 43}{\frac{v_1}{v_0} - 0 \cdot 57} \right)^{2 \cdot 474} dx,$$

and as was found before the part under the integral becomes $\left(\frac{1}{0 \cdot 0219\, x + 1}\right)^{2 \cdot 474} dx$, of which the integral is

$$-\frac{1}{1 \cdot 474 \times 0 \cdot 0219\, (0 \cdot 0219\, x + 1)^{1 \cdot 474}},$$

and taking this between $x = L$ and $x = o$

$$30 \cdot 98 - \frac{30 \cdot 98}{(0 \cdot 0219\, L + 1)^{1 \cdot 474}}, \text{ and since } L = 25 \cdot 5$$

$$= 30 \cdot 98 - \frac{30 \cdot 98}{1 \cdot 923} = 30 \cdot 98 - 16 \cdot 11 = 14 \cdot 87.$$

Therefore work done $$= \frac{3 \cdot 1416}{13{,}000} \times 1 \cdot 333 \times 25 \times 18^2 \times 14 \cdot 87$$

$$= 42 \cdot 04 \text{ foot-tons.}$$

Stretching the guns between breech and trunnions.

The expression for this is

$$\frac{\pi (R^2 - \rho^2)\, l\, P_1^2}{E\, (m^2-1)^2},$$

which since $$(m^2 - 1) = \frac{R^2 - \rho^2}{\rho^2} \text{ becomes}$$

$$\frac{\pi \rho^4\, l\, P_1^2}{E\, (R^2 - \rho^2)}$$

$$= \frac{3 \cdot 1416 \times 625 \times 25 \cdot 5 \times 18^2}{13{,}000 \times 75} = 16 \cdot 64 \text{ foot-tons.}$$

Determination of Δ V.

This is made up of

(*a*) *Vis viva* of projectile $= \dfrac{W}{g}\, u^2$.

$$\therefore \text{Work done} = \frac{W\, u^2}{2\, g\; 2{,}240} =$$

$$= \frac{500}{64\cdot 4 \times 2{,}240}\, u^2 = 0\cdot 003465\, u^2 \text{ foot-tons.}$$

(*b*) *Vis viva* of gun and carriage. The weight of the gun is 27 tons, and if the resisting part of the carriage be taken at one-third the weight of the gun, or 9 tons, then $W_1 = 36$ tons. Therefore

$$\text{Work done} = \frac{W_1}{2\, g} \cdot u_1^2 = \frac{36}{64\cdot 4}\, u_1^2 = 0\cdot 559\, u_1^2 \text{ foot-tons.}$$

(*c*) *Vis viva* of the gases, or

$$\int u_{\prime\prime}^2\, \delta\, \mu.$$

The value of this is

$$\frac{W}{3\, g}\,(u^2 + u_1^2 - u\, u_1).$$

Therefore work done in foot-tons

$$\frac{300}{6\, g \times 2{,}240}\,(u^2 + u_1^2 - u\, u_1) = 0\cdot 0006931\,(u^2 + u_1^2 - u\, u_1) \text{ foot-tons.}$$

Determination of $\int R\, d\, x$ the resistance of the air due to the velocity.

Now $\qquad d = 10$ inches, $\qquad W = 500$ lbs.

To find a from Table II. of the Reports on Experiments made with the Bashforth Chronograph, above referred to, it will be seen that the resistance to a 10-inch ogival-headed projectile at 1,000 feet per second is 233 lbs., and as the resistance is as the cube of the velocity the resistance at velocity $V = 233 \left(\dfrac{V}{1{,}000}\right)^3$

$$= 0\cdot 000000233\, V^3 \qquad \therefore a = 0\cdot 000000233,$$

but the velocity is approximately $= 744\ S^{\frac{1}{3}}$ = therefore the resistance $= (744)^3 \times 0\cdot 000000233 \int S\, \delta\, s = 95\cdot 95 \int S\, \delta\, s$, which when $S = L = 47\cdot 97\, L^2$, and when $L = 25\cdot 5$ the above [illegible] $13\cdot 89$ foot-tons.

Therefore

$J \Delta Q$ or equivalent of heat absorbed . .	1,850 foot-tons.	
ΔI „ internal work = 0.		
A W (*a*) Expulsion of air	13·89	„
(*b*) Rotation	$0\cdot00002\, u^2$	„
(*c*) Friction of gas-check, &c.. . .	286·9	„
(*d*) „ of gases . . .	$0\cdot00002765\, u^2$	„
(*e*) Stretching guns—		
In chamber . . . 15·80		
Chase . . . . . 42·04		
Longitudinally . . 16·04		
	73·84	„
ΔV on projectile	$0\cdot003465\, u^2$	„
„ „ gun and carriage	$0\cdot559\ u_1^2$	„
„ „ gases . .	$0\cdot0006931\,(u^2 + u_1^2 - u\,u_1)$	„
$\int R\, d s$ Resistance of air	13·89	„

Now all this work is done by the gases, and should be equivalent to $J \Delta H$, the equivalent of the heat expended, and which has been already found = 19,513 foot-tons.
Therefore

$$19{,}513 = 1{,}850 + 13\cdot89 + 0\cdot00002\, u^2 + 286\cdot9 + 0\cdot00002765\, u^2 + 73\cdot84 + 0\cdot003465\, u^2 + 0\cdot559\, u_1^2 + 0\cdot000693\,(u^2 + u_1^2 - u\,u) + 13\cdot89\,;$$

or

$$17{,}275 = 0\cdot0042056\, u^2 + 0\cdot559693\, u_1^2 - 0\cdot000693\, u\, u_1,$$

but as shown above

$$u_1\, u_1 = W\, u + \frac{w}{2}\,(u - u_1),$$

from which

$$u_1 = \frac{W + \frac{w}{2}}{W_1 + \frac{w}{2}} \cdot u$$

and

$$W = 500, \qquad w = 300$$

$$W_1 = 36 \times 2{,}240, \text{ therefore}$$

$$u_1 = \frac{650}{80{,}790} \cdot u = 0\cdot008046\, u$$

substituting this value in the above equation

$$17{,}275 = 0\cdot0042056\,u^2 + 0\cdot0000362\,u^2 - 0\cdot000005576\,u^2$$
$$= 0\cdot0042362\,u^2$$
$$\therefore u = 2{,}020 \text{ feet per second,}$$

which is the muzzle velocity,

and u_1 = velocity of recoil = $0\cdot008026 \times 2{,}020 = 16\cdot25 f s.$

and

Work done for rotation = $0\cdot00002\,u^2$ = $81\cdot62$ foot-tons;
„ friction of gases = $0\cdot00002765\,u^2 = 112\cdot78$ „
„ on projectile = $0\cdot003465\,u^2$ = 14,107 „
„ on gun and carriage = $0\cdot559\,u_1^2 = 147\cdot61$ „
„ on gases = $(0\cdot0006931)\,(u^2 + u_1^2 - u\,u_1) = 2{,}828$ „

Summary of work done—

On projectile	14,107	foot-tons;
On gases	2,828	„
On gun and carriage	148	„
On rotation	82	„
Friction of gas-check	287	„
Expulsion of air	14	„
Friction of gases	113	„
Resistance of air to shot	14	„
Stretching of gun	74	„
Equivalent of heating gun	1,850	„
Total	19,517	„
Total J Δ H =	19,513	„
Difference	4	„

The total heat developed per kilogram of powder, according to Noble and Abel is

$721\cdot400$ French units
= $1{,}298\cdot4$ English units per lb.

Therefore the equivalent work of 300 lbs.

$$= \frac{1{,}298\cdot4 \times 300 \times 772}{2{,}240} = 134{,}260 \text{ foot-tons}$$

of which there is expended

In the gun	19,517	foot-tons.
Loss	114,743	„

The amount actually utilized in the shot is 14,107 foot-tons.

The whole of the above loss is in the residual power of the gases as they escape into the atmosphere at an absolute temperature of 3,652° Fahrenheit.

The loss to be accounted for is 114,743 foot-tons. Now the equivalent work remaining in the gases if reduced down to 542° Fahrenheit (absolute) = 51° of Fahrenheit

$$= \frac{300 \times 0\cdot3381 \times 772 \times (3{,}652^\circ \dot{-} 542^\circ)}{2{,}240} = 108{,}850 \text{ foot-tons,}$$

leaving a remainder of 5,893 foot-tons still in the gases.

The velocity of the projectile, as determined by the above calculation, is 2,020 *f.s*, and the energy 14,107 foot-tons.

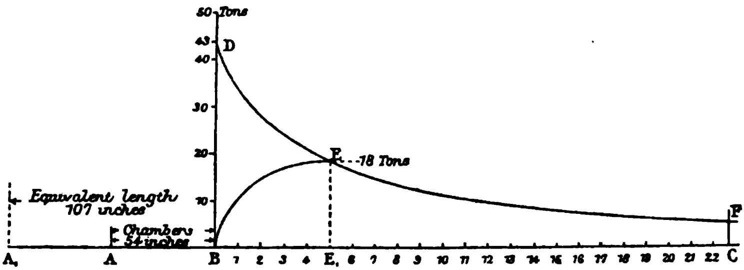
It is stated by Mr. Anderson in a Lecture delivered before the Society of Arts,[1] that the velocity was 2,100 *f.s*, but it is not said whether this was the observed or only the estimated velocity.[2]

Supposing it to be the former, it gives 15,280 foot-tons for the energy of the projectile, which exceeds the calculated energy by 1,173 foot-tons.

It is very possible that a good deal of this difference may be attributable to an overestimate of the amount of heat communicated to the gun, and which has been estimated above at the equivalent of 1,850 foot-tons.

A few carefully-conducted experiments would throw much light on this subject. Enough, however, has been done in this Paper to show that the actual muzzle-velocity may be very approximately estimated without reference to the actual pressure of the pressure-curves.

The following figure illustrates the method usually adopted by the Author, for estimating the muzzle-velocity from the pressure-curve:—



[1] "Journal of the Society of Arts." Vol. xxxiii., p. 727.

[2] The observed velocity is somewhat greater than the real muzzle velocity, because the gases do not cease their action on the projectile immediately on its quitting the muzzle.

A B represents the length of the powder-chamber.

A_1 B its equivalent length, if of the same diameter as the bore.

B C represents the chase outside the chamber.

In the present case the charge of 300 lbs. at 27·7 cubic inches to the lb. would just fill the chamber, or its equivalent length.

D E F represents Noble and Abel's curve calculated from the formula

$$p = p_o \left(\frac{v_0 (\iota - a)}{v - a v_0} \right)^{\frac{Cp + \beta a}{Cp_1 + \beta a}}$$

which is numerically

$$p = p_o \left(\frac{0 \cdot 43}{\frac{v}{v_0} - 0 \cdot 57} \right)^{1 \cdot 0748}.$$

E is the point in this curve where the pressure is 18 tons per square inch, the observed maximum pressure which is attained when the projectile has reached the corresponding point E.

After this point the work on the projectile is represented by the area E_1 E F E_1.

Previous to this the projectile has been acted on by an increasing pressure, which would be represented by a curve rising vertically from B and terminating horizontally at E. The exact form of this curve is at present unknown, but the Author has assumed it to be elliptical, and he therefore adds the area of the quarter ellipse B E E to the area E_1 E F E, and this sum he takes to represent the work done on the shot and the gases per square inch of the bore.

In the present instance this area is 231, which, multiplied by 78·54, the area of the other gives 18,142 foot-tons.

Now, by the preceding calculation, the energy accounted for was found to be:—

	Foot-Tons.
On the projectile for velocity	14,107
„ for rotation	82
„ friction	287
	14,476
Expulsion of air	14
Resistance of air	14
Giving velocity to the products	2,828
Friction of ditto	113
Recoil velocity	148
Total	17,693
Energy from curve	18,143
Difference . .	450

Which may probably be due to a slight escape of the gases before the gas-check comes fully into action, or to a slight amount of windage from its not exactly sealing the bore.

The difference is, however, so small that it confirms the Author in his method of estimating the velocity from the pressure-curve, deducting from the area of this curve about 22 per cent. for work done in giving rotation, overcoming friction, giving velocity to the gases, &c., &c.

The difficulty, however, in applying this method is, that it involves the prior knowledge of the maximum powder-pressure, which at present there is no *à priori* method of determining.

One advantage is claimed for the method in the preceding calculation by Count de St. Robert, who observes that it seems to eliminate all consideration of the mode of combustion of the charge.

He says, "Principes de Thermodynamique," p. 252—Whatever be the mode of combustion in the guns, whether it burns instantaneously or successively, the two temperatures t_0 and t are always the same. The first depends on the composition of the powder, and is determined by the chemical reaction which takes place whilst it passes to the gaseous state. The second depends only on the ratio of the space occupied by the gases whilst they have the temperature t_0 to the space they occupy when they are expanded in the chase, when the projectile leaves the muzzle, and on the atmospheric pressure—quantities which remain invariable.

The Author is not prepared to admit the correctness of this remark without limitation, as it seems contrary to the thermodynamic law that "any thermal machine which works between given limits of temperature gives the maximum useful effect when all the heat is received at the highest temperature and rejected at the lowest."[1]

It is evident from an inspection of the curve given above that the effect of the powder must increase as the point E_1 approaches to B—that is to say, as pressure accumulates more rapidly behind the projectile, or as the powder burns quicker.

The Author, therefore, sees no reason to alter the views he has so often expressed about slow-burning powder.

[1] The error in Count de St. Robert's remark seems to be that he makes t_0 and t both invariable. But this is not consistent with the fact that $t = t_0 \left(\dfrac{0 \cdot 43}{\dfrac{v}{v_0} - 0 \cdot 57}\right)^{0 \cdot 074}$, because v_0 is the volume when the temperature is t_0, and this volume is less as the rate of burning of the powder is greater.

He proposes on a future occasion to treat at some length on this subject, it being foreign to the purpose of the present Paper.

What he thinks he has established in this communication is that it is quite possible to estimate very approximately the ballistic effect of a gun from purely thermodynamic principles.

The Paper is accompanied by a diagram, from which the figure in the text has been engraved.

(*Paper No. 2074.*)

"Standard Engine Shed of the London and North Western Railway Company."

By Francis William Webb, M. Inst. C.E.

The standard type of locomotive-engine shed designed by the Author, and which has been adopted by the London and North-Western Railway Company since 1874, and erected at most of their principal stations, is shown in Plate 4. This gives particulars of two large sheds, with repairing-shops between, as erected at Rugby. Each shed is capable of holding sixty engines and tenders, and both complete with the necessary offices, which are arranged at the back of each shed. Attention has been paid, in designing the sheds, to have all the parts made to template, so that no fitting is required on the ground. The roof is of the ordinary weaving-shed, or "saw-tooth" pattern, and the ridges run at right angles to the rails. The roof forms a series of 15-feet spans, while the beams, from which each bay springs, are supported at intervals of 25 feet 6 inches by cast-iron columns (which are also used as down-spouts for rain-water), the space between the columns being sufficiently wide for two lines of rails. Over each line of rails, and extending from end to end of the shed, are wooden partitions, sufficiently wide apart to admit the engine-chimneys between them, and projecting down to within 12 feet 6 inches of the rail-level. These partitions form a kind of inverted trough for collecting the smoke from the engine-chimneys, and the smoke is discharged through a short wooden chimney at the apex of the roof of each span.

The system of glazing adopted is simple and effective, entirely doing away with the necessity of putty. The sash-bars are dove-tailed on each side to receive the glass, which is in one piece, and one side is cut deeper than the other, so that the glass can be put in sideways, while a stop-piece is fixed in the deeper grove at the top of the bar, to keep it from moving laterally when in its normal position. A piece of bent galvanized iron, carried on the bottom rail, supports the glass when in position. The pits are

paved with blue bricks, and their bottoms made to slope to one side, along which the drain is carried, so that water cannot accumulate in the centre. The floor of the shed between the pits is is also paved with blue bricks, and made to slope towards the rails, where a number of small grids are placed to admit of the passage of the water into the pits when an engine is being washed out.

It will be seen that the system of construction here employed is one that is suitable to any desired extension, either laterally or longitudinally, and is well adapted for the purpose for which it was designed, giving plenty of light and ventilation, while at the same time it is capable of being erected at a cost much below that of such structures generally. Another advantage is that this type of shed is much warmer in the winter than those with the ordinary louvre ventilators, so that no fires are necessary to prevent the water from freezing in the engines.

This Paper is accompanied by a tracing from which Plate 4 has been engraved.

(*Paper No. 2065.*)

"Cost of Dredging at Calais and at Boulogne."

By F. Guillain, Engineer-in-Chief of the Ports of Boulogne and Calais.

(Translated by F. G. Delano.)

The dredging of the entrance of the old harbour of Boulogne is let to a contractor, who supplies his own plant, and works at his own risk at the following prices:—

1. *Sand.*—The boat employed is a steam hopper-dredge, furnished with a sand-pump, aspirating a mixture of sand and water. The operations are performed in the open sea, in front of the jetties, whenever the height of the swell does not exceed 3 feet for head-waves, and 1½ foot for cross-waves. The spoil is taken out to sea by the dredge for about 2 miles and there dumped. For this service, the contract price is 1 franc per cubic metre (about 7¼*d.* per cubic yard). The present contract has nearly run out, and the contractor is willing to renew it at 90 centimes per cubic metre (6½*d.* per cubic yard), if he is guaranteed a year's work of 160,000 cubic metres. If the port authorities would grant him a contract of 800,000 or 900,000 cubic metres, to be accomplished in five or six years, he would take 75 centimes per cubic metre (4⅝*d.* per cubic yard), on condition of being allowed to work also at Calais when weather permitted.

For similar work, the price paid at present at Calais is 92 centimes per cubic metre. Similarly, the work could be done for 75 centimes on guaranteeing the contractor continuous employment of his plant for five or six years, on a contract including both Calais and Boulogne.

The Author has made a careful calculation of the probable cost to the contractors at these two ports for the working of their plant. For fuel and stores, wages, and ordinary repairs, but not including interest, sinking fund, nor contractor's profit, he estimates an average effective cost of 35 centimes per cubic metre for Calais, and 46 centimes per cubic metre for Boulogne, the material being

dredged in front of the port and dumped out at sea. If the contractor, in consideration of tendering at the lower figure of 75 centimes per cubic metre, is allowed to work either at Calais or Boulogne, and to take a contract sufficient to ensure the employment of his plant for several years, the sinking fund will become a less important item. On the other hand, the periods of westerly winds unfavourable for working at Boulogne can be utilized at Calais, while the periods of northerly and easterly winds unfavourable at Calais can be utilized at Boulogne, thus necessitating one plant only for the two sites.

Details will now be given of the above-mentioned figure of 46 centimes per cubic metre as the cost price of dredging in the open sea in front of the Boulogne jetties.

The work was done, successively or simultaneously, by three screw steam hopper-barges furnished with sand-pumps, viz., the "Maasmond IX.," the "Adam VII.," and the "Boulogne I.," of which the principal dimensions are:—

——	Maasmond IX.	Adam VII.	Boulogne I.
Length	34 m. (111½ ft.)	42 m. (138 ft.)	42 m. (138 ft.)
Beam	7·75 metres.	8·25 metres.	8·25 metres.
Depth	3·05 "	3·38 "	3·38 "
Capacity of the hoppers	161 cub. metres.	245 cub. metres.	245 cub. metres.
Indicated horse-power of the engines (high-pressure non-condensing)	120 I.HP.	216 I.HP.	216 I.HP.
Monthly wages of the crew—	Francs.	Francs.	Francs.
1 captain, chief dredger	260 (£10 7 6)	260	260
1 engineer	260	260	260
2 stokers	380 (£15 5)	380	380
Seamen (3 for the Maasmond IX.; 4 for the others)	570 (£22 16)	760 (£30 7 6)	760
Dredger worked at Boulogne	22 Apr. 1883, to 25 June, 1884.	25 June, 1884, to 3 Sept., 1884.	12 June, 1882, to 20 Jan., 1885.

—	Maasmond IX.	Adam VII.	Boulogne I.
During each of these periods the total effective expenditure of the contractor was—	Francs.	Francs.	Francs.
Wages of the crews . . .	21,904·20	3,590·48	49,542·12
Coal at an average of 23 francs per ton	22,443·00	3,565·00	49,459·00
Other stores (fresh water, oils)	6,064·90	1,244·00	16,144·35
Maintenance and repairs . .	21,177·75	6,434·50	61,311·70
Total	71,589·85 2,864)	14,833·98 (£593)	176,457·17 (£7,058)
The total amount dredged and discharged, on the average, 2 miles out at sea during the periods indicated, was . .	157,869 cub. m.	32,146 cub. m.	379,858 cub. m.
During each of these periods each dredger was at work—	Hours.	Hours.	Hours.
Dredging	1,817	402	3,992
Under way to the dumping-ground and returning to the site	1,157	205	2,348
The cost price per cubic metre of sand was therefore—	Francs.	Francs.	Francs.
Wages of the crew	0·138	0·112	0·130
Coal	0·142	0·112	0·130
Stores	0·038	0·039	0·042
Maintenance and repairs . .	0·134	0·201	0·161
Total[1]	0·452	0·464	0·463
Proportional cost, time employed—	Francs.	Francs.	Francs.
Dredging	0·276	0·307	0·291
Transport	0·176	0·157	0·172
Cost of a dredger on the slip at Rotterdam	120,000	138,000	138,000

The state of the sea before Boulogne in respect of dredging was:—

—	Number of Tides when the rise of the Swell was—			
	Above 0·70 metre.	From 0·70 to 0·60.	From 0·60 to 0·50.	Below 0·50.
In 1882 . .	392	20	35	260
„ 1883 . .	324	41	54	286
„ 1884 and to 20 Jan. 1885	258	15	19	451

[1] Averaging 45·9 centimes per cubic metre, or 3·34*d.* per cubic yard.

The following Table shows the number of tides missed, by a dredger, the "Boulogne I." for instance, and the causes of this enforced idleness :—

——	Cause of Non-work.			Totals.
	Rough Sea.	Repairs.	Fête-days.	
In 1883 . .	284	24	7	315 tides missed out of 705
„ 1884 and to 20 Jan. 1885	256	68	21	345 tides missed out of 743

2. *Material other than Sand.*—Besides the before-mentioned pump-dredger there are employed at Boulogne, for deepening the inner port, in parts where the bottom is not sandy, two powerful bucket-dredgers, discharging their dredgings into hopper-barges, which are towed to the dumping-ground 2 miles distant. The plant belongs to the contractor, and he is paid 1 franc 55 centimes per cubic metre (12·28*d.* per cubic yard) measured in the hold of the barge. This price is for ordinary material such as mud and sand mixed with stones brought down by the river, deposited by the sea, and covering the original bed; but for the extraction of the hard soil underneath this material, an additional amount of 4 francs 45 centimes per cubic metre (32·38*d.* per cubic yard) is allowed. This extra is for the compact schistose clay, as hard as tufa, which constitutes the bulk of the bed. Furthermore, for beds of rock more than 25 centimetres (10 inches) thick, an addition of 12 francs per cubic metre (70·4*d.* per cubic yard) is paid. In the schistose (Kimmeridge) clay, there are found beds of hard limestone, from 60 to 80 centimetres thick, fortunately cracked, which the dredgers bring up in pieces by applying the buckets underneath. Occasionally recourse has to be had to dynamite exploded on the surface of the rock. The extent of the beds of rock for which the higher amount—12 francs—is paid, is determined by borings made very closely together before the work is begun. In the same way the amount of the clay for which 4 francs 45 centimes is paid, is determined. A profile is made of the hard clay, and to the volume thus calculated, one of the two extra rates is applied; then the whole material, sand, stones, clay, boulders, &c., deposited in the barges, is measured, and 1·55 franc per cubic metre allowed for the bulk.

From estimates of the cost of working, it appears that these

extra charges are not excessive; for the boulders and the clay cause continual damage to the buckets, and the cost of repairs is very heavy. Doubtless a much lower rate would have been paid had more powerful plant been employed, made specially to cope with refractory material, as are some of the dredgers on the Clyde and the Tyne. But the small extent of the hard stuff to be got out at Boulogne to attain the necessary depth of water, has not justified the cost of such plant, and it has been found cheaper to utilize the existing dredgers with which it is only necessary to change the buckets. This explains the high rate paid for dredging hard stuff at Boulogne.

From the beginning of the operations (13th April, 1883,) until 31st December, 1884, there was dredged, inside the port, a volume of 149,000 cubic metres measured in the barges. The total paid for as banks of rock measured on profile was 4,800 cubic metres, and the total paid for as schistose clay was 26,600 cubic metres. At the present time the contractor is losing money, as may be seen from the subjoined Table of details. Up to January, 1884, the plant consisted of a single dredger; since then two have been employed working simultaneously. The dredgers are served together by four hopper-barges of 100 cubic metres capacity, and by one tug.

The largely-varying prices for each dredger are due to the following causes: 1st. The "Boulogne II." had more hard material to get out than the two other dredgers, and the "Nieuwemaas VI." more than the "Nieuwemaas V." 2nd. The "Boulogne II." had buckets stronger but smaller than those of the other boats. The "Nieuwemaas VI." and the "Nieuwemaas V." were specially intended for working in soft clay, sand, and mud; they were, however, often obliged to attack hard ground, and these injured their buckets.

It will be noted that the total cost to the contractor up to the end of 1884 already amounted to 430,000 francs. Now by his contract, the cube extracted will only yield him 420,000 francs. He is, therefore, at present suffering a loss which can only be recouped to him in case he dredges a larger proportion of hard material. The surcharge of 4·45 francs for dredging hard clay is thus really advantageous to the authorities.

—	Bucket-Dredgers. Nieuwemaas V.	Bucket-Dredgers. Nieuwemaas VI.	Bucket-Dredgers. Boulogne II.	Tug and Barges.
Working-time of each element of the plant	Arrival 13 Apr. 1883; Departure 15 Mar. 1884	Arrival 20 Jan. 1884; At work to 31 Dec. 1885	Arrival 23 Apr. 1884; At work to 31 Dec. 1884	Arrival 13 Apr. 1884. At work to 31 Dec. 1885.
	Metres.	Metres.	Metres.	
Length	33	33	37·25	..
Beam	6	6	6	..
Depth	2·80	2·80	2·90	..
	HP.	HP.	HP.	
Nominal horse-power	40	40	70	..
	Kilog.	Kilog.	Kilog.	
Boiler-pressure—kilograms per square centimetre = 14·22 lbs. per spuare inch	5	5	5	..
	Litres.	Litres.	Litres.	
Capacity of a bucket for silt, soft clay or sand	320	320	..	..
Ditto for schistose clay	..	..	215	..
Number of buckets traversing per minute in mud, soft clay or sand	15	15	..	..
Ditto in schistose clay	..	..	8 to 10	..
	Francs.	Francs.	Francs.	Francs.
Monthly wages of the crew: 1 captain	260	260	260	300
Monthly wages of the crew: 1 engineer	260	260	260	260
Monthly wages of the crew: 1 stoker	190	190	190	190
Monthly wages of the crew: Seamen (5)	950	950	950	390 (2 seamen)
	Francs.	Francs.	Francs.	Francs.
Total effective cost to the contractor during the progress of the work above-mentioned: Wages of crew	30,465·36	27,822·28	12,923·00	24,915·92
Fuel	13,527·00	17,169·00	14,384·00	29,606·00
Stores	7,334·60	9,795·60	7,082·60	5,880·30
Repairs and maintenance	71,172·55	73,005·10	62,073·50	14,335·60
Total	122,499·51	127,791·98	105,463·10	74,737·82
	Cub. met.	Cub. met.	Cub. met.	Cub. met.
Total volume dredged and transported	62,603	53,757	30,848	147,208
Average cost per cubic metre—	Francs.	Francs.	Francs.	Francs.
Dredging	1·956	2·377	3·418	..
Transport 2 miles out to sea	..	..	..	0·507
Total number of hours worked	2,448	1,958	1,789	2,265

(*Paper No. 2079.*)

"Brauer's Dynamometric Brake."[1]

By H. Walther-Meunier.

(Translated and Abstracted by B. H. Thwaite, Assoc. M. Inst. C.E.)

Two striking characteristics distinguish this brake, the invention of Mr. Brauer, from others of the same class. Firstly, it does not require when in action that its frictional surfaces should be constantly wetted: with ordinary wooden brakes this is absolutely necessary. Secondly, once the clutching action is established the brake regulates itself automatically, and further, there is not required, as with the ordinary brake, a long and cumbersome lever. An analogous arrangement to that of Mr. Brauer has been suggested by Mr. Kratz in his essay upon the dynamometric brake.[2]

In the Brauer apparatus, instead of wooden jaws hugging the rims of the pulley, an iron band is used for flat-rim pulleys, and wire-ropes for grooved pulleys. The apparatus is composed of the following assemblage of parts:—

1st. The iron band or wire-rope.

2nd. The clutch-producing arrangement and the regulation of the tension of the clutch-producing bands or ropes.

The clutch or pressure of the bands or ropes upon the surface of the rim of the pulleys produces a friction corresponding to the effective work of the motor. The moment of this friction multiplied by 2π gives the work produced per revolution. To calculate this it only needs to determine an equal moment given by the additional charge or weight p, augmented by the weight of the regulating organs, the two weights affixed to the axis of the

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[1] The original artiele appeared in the "Bulletin de la Société Industrielle de Mulhouse," 1884, p. 485.

[2] "Memoire sur les conditions à remplir dans l'emploi du frein dynamométrique," par M. Kratz, ingénieur en chef, inspecteur des manufactures de l'Etat. Paris, 1873.

pulley, and p the moment required to maintain the system in equilibrium. The iron band applied to an ordinary flat-rim pulley is provided with four double guides k (Fig. 1, Plate 6) to retain the band in position, which is fixed up from the under-side by means of a stirrup bolt and link and a safety cord l^1 l^2, in such a way as to allow the band to have a play of 100 millimetres. These safety measures can be modified according to local circumstances, and when the under part of the pulley or drum is inaccessible.

The clutching or frictional parts are actuated in the following manner:—

The wire band is attached at its two ends in one instance to the point of the application of resistance a, and in the other to the point of rotation b by a lever $a\,b\,c$. The point c of this lever is attached at d by means of a winding tackle $e\,e_2$, and a spring f, to the upper end of the wire band. The cord of the winding tackle after leaving e is passed round the friction-roller g. The operator by slightly pulling the cord will be able to produce the tightening or clutching action in such a way that the weight p is lifted up and equilibrium established. In order that this condition may not be influenced by the tension of the part of the cord from e_2 to g, it is only necessary to fix the friction-roller in such a way as to be in line with the axis of the pulley or drum. The moment of this tension will then be nil. The friction-roller is not absolutely indispensable, but its application permits the operator to control and watch the action of the dynamometric brake at some distance from it. The automatic regulation is effected, according to the variations of the friction, by the combined action of the coil-spring f and the cord h. It will be seen that if, owing to the band producing excessive friction, the weight p is lifted above its mean position, the cord h will be stretched, augmenting the tension, and consequently elongating the coil-spring f. The result is a diminution of the clutching action of the band, and the weight p will be lowered.

The weight l, which replaces the necessity of attaching the cord h to the floor-boards, should be sufficiently heavy to equal the strain liable to be brought upon the cord h.

The lifting-tackle should always be suspended in such a way as to reduce the traction upon the cord h to a minimum, and so that the influence of this factor upon the condition of equilibrium in general need not be taken into consideration.

The effective work performed can be ascertained by the following formulas:—

$$T = \frac{(P + p)\,L\,\pi}{716 \cdot 2} \text{ horse-power.}$$

In which T = the effective work in horse-power;
P = the load-weight in kilograms;
p = the weight in kilograms of the regulating organs suspended to the point of attachment P;
L = the distance from the centre of the pulley to the point of attachment of the weight in metres;
n = the number of revolutions per minute.

Lubrication is effected by means of oil lubricators placed at the position marked *a* (Fig. 1). It is useless to try to cool the frictional surfaces by the use of water. If the pulley-rim presents to the surrounding air a surface equal to 10 square decimetres per HP., then the rim may be allowed to attain a temperature of as much as 100° Centigrade (212° Fahrenheit) without inconvenience. These conditions are generally realized by the flat rim or band pulleys, and by grooved pulleys, in each groove of which there is provided a wire rope of from 7 to 8 millimetres in diameter. For brakes of small dimensions the tackle arrangement can be advantageously replaced by means of a tightening screw. In the case of a vertical shaft the weight may be attached to a bent lever, or to a chain passing over a friction-roller.

The use of the tackling arrangement is only very rarely required, seeing that the condition of equilibrium is maintained with great uniformity.

Care must, however, be taken to attach the cord very firmly, so that in case of need the tightening or clutching action can be instantly diminished or increased.

The following is a description of the dynamometric brake employed by Mr. Walther-Meunier to test the Brauer principle.

The application was made to a four-grooved pulley 2·15 metres (7 feet) in diameter, measured from the base of the grooves. The intention of the application was to measure the effective work performed by a 25-HP. engine.

The under portion of the pulley for a quarter of the π ran in a cemented race; it was therefore necessary to have recourse to a precautionary measure different from those already described. Figs. 2 to 8 show the arrangement devised by Mr. Brauer especially for this purpose. Each of the grooves was provided with a wire rope A A in two portions, one passing over the pulley, the other under. One of the ends of the upper portion was attached to the skate B (Fig. 3), a sketch of which, and enlarged, is shown

(Fig. 2). The other end is attached to the double hook C (Fig. 3). The under wire rope is twisted round the hook C, and is attached at its other extremity to the rim of a stirrup D (Figs. 3 and 7), furnished with a boss E, through which there works a tightening screw F, provided with an actuating handle or wheel.

The iron skate B (Fig. 3) is perforated obliquely to receive the lubricating medium from a needle lubricator G. One end of the bent bar H is firmly let into the skate B; the apex of this bent bar H is twisted so as to carry the suspension-bar I, firmly held in position by two nuts at its two ends.

This suspension-bar carries the stirrups J (Fig. 8), upon which rest the plates K for receiving the weights. The suspension-bar also carries the bent lever L. This lever is provided with a bolt M, upon which the pressure of the tightening screw F (Fig. 3) is exerted. The other end of the bent lever L is attached by a wire cord N to the floor, and also to the regulating apparatus, by means of a thin steel band O attached to the hook C, which through the coil-spring P is in direct communication with L. The complete arrangement of the brake is composed of four systems, similar to that already described, one for each groove of the pulley.

The brake being in perfect equilibrium, the centre of the highest end of the lever L was about 1 metre (3 feet 3 inches) above the ground, and the cords N were arranged so as to be neither too slack nor too tight, but all about the same tension. In order to indicate the perfection of equilibrium, Mr. Brauer alternately relaxes and extends these cords. In this way the slightest variable resistances impossible of avoidance are compensated for in a sufficient manner.

In the event of the breakage of one of the parts, the hook C is caught on the cross-piece of the framework support Q. The coil-springs P, owing to their attachment to the long bar of the lever L are never subjected to a greater strain than 10 kilograms (22 lbs.).

In order to put the brake in action, the suspension-bar I should be placed exactly at the height of the centre of the axis of the pulley, and in the instance of the application above described, the centre of the eye of the highest end of the lever L is about 1 metre above the ground. The cords N and the highest screw-attachments P should then be fixed.

Before applying the brake, it should be ascertained whether the pulley turns in the direction shown by the arrow (Fig. 3) without dragging the brake. The lubricators should now be examined, and a little oil should be poured into the grooves of the pulley. After weights are placed on the weight-suspender the tightening screw should be very gently turned until it lifts the weights from

the platform, and leaves them in gentle state of oscillation near the condition of equilibrium. If the tightening screw is applied too violently, the cords will be extended without lifting the weight.

The following is a summary of the observations made by Mr. Burghardt, who has carefully tested Brauer's dynamometric brakes. Needle-lubricators do not sufficiently lubricate the apparatus; tallow is preferable as the lubricating medium. The brake worked well during the time the temperature of the pulley-rim did not exceed 35° to 40° Centigrade, and even up to 80° Centigrade the action was still satisfactory, but the lubricating medium became too fluid, and was thrown off the grooves by the centrifugal force due to the speed of the pulley. The Brauer brake worked well for two hours with a load corresponding to 25 HP.

Summary of the advantages and disadvantages of the Brauer brake over those of the ordinary description:—

1. The necessity of continually cooling the pulley-rim by subjecting it to a stream of water, which is a great drawback to the use of ordinary brakes, is in the Brauer brake avoided.

2. The brake is not so cumbersome, and can be applied to motors *in sitû*, and in confined spaces.

3. The oscillations are very limited, and consequently the observations are more exact than with the ordinary brake, and the diagrams obtained by the indicator are clean and clear, and easy to calculate.

On the other hand, the Brauer brake is relatively rather more costly than those of the ordinary class, and it requires in its application a little more care than those of the ordinary and unscientific class.

The excellence of the Brauer brake is such that Messrs. Walther-Meunier and Burghardt decided to utilize it in their investigations of the following important questions:—

1st. Whether it is advisable to work a steam-engine with or without condensation.

2nd. Whether it is advisable to work with low pressure and low expansion, or with high pressure and high expansion.

3rd. What is the variation of the effective work under different loads.

The motor used in order to investigate these questions was on the Collman system, having four distributing-valves, two for inlets and two for exhaust, the former having variable expansion gear. The engine was also provided with a condenser. The mechanical parts of the engine were perfectly balanced. The engine had a piston-stroke of 600 millimetres (about 24 inches).

Its piston was 301 millimetres (12 inches) in diameter. The engine was worked at 70 revolutions per minute.

The net weight of the brake was established as suggested by Mr. Brauer neglecting the weight of the iron bands or wire-ropes, coiled springs, &c. The following details enter into this account:

Distance from the centre of the pulley axis to the point of attachment of the weights	1·185 metre.	
Weight of the four *c i* skates	31·50 kilograms.	
,, ,, lubricators	0·90 ,,	
,, load carriers or suspenders . . .	10·20 ,,	
,, attachment levers	39·25 ,,	
Total	81·85 ,,	(180 lbs.)
Deduct the weight of the four safety hooks . . .	6·50 ,,	
Net weight of the brake =	75·35 ,,	(166 lbs.)

Corresponding at 70 revolutions to the work, equivalent to 8·727 HP., or

$$T = \frac{1}{716 \cdot 2} \times 75 \cdot 35 \times 70 \times 1 \cdot 185 = 8 \cdot 727 \text{ HP.}$$

The number of revolutions per minute was registered by a counter connected to the main shaft.

Twenty diagrams were taken at each end of the cylinder, all those indicating any irregularity in the working of the brakes being eliminated. The following is a summary of the conclusions arrived at by Messrs. Walther-Meunier and Burghardt:—

1st. It is desirable to work a steam-engine with a load proportionate to its dimensions.

2nd. It is desirable to employ condensation where local circumstances will permit, even for engines of comparatively small dimensions, on the condition that the condenser and its actuating mechanism are carefully and intelligently proportioned.

3rd. It is desirable, even with single-cylinder engines, to work with the highest pressure.

4th. It is highly desirable that every possible precaution should be taken to ensure a perfect and continuous lubrication of the frictional parts of all steam-engines without exception. The serious study of lubricating methods and lubricants deserves the attention of all steam-users.

The illustrations which accompanied the original article have been reproduced in Plate 6.

(*Students' Paper, No. 185.*)

"Secondary Batteries."[1]

By Frank Geere Howard, Stud. Inst. C.E.

Among the most important discoveries of recent years few have received so much attention, and had such bright prospects, as the accumulators of Planté and their various modifications. All sorts of wild schemes were set afloat for their utilization, the principal one being to talk about the time when electricity by means of these accumulators could be delivered every morning from house to house like milk. The result of this would have been much the same as if a water company attempted to supply water to its customers by sending round so many gallons every day in carts, or better still a gas company delivering bags full of gas ready for use, one being as impracticable as the other. These ideas were soon dispelled, and then followed disappointment, and of course general condemnation of secondary batteries.

But all this time inventors had been steadily turning their attention in this direction. Many improvements have been introduced, and numbers of difficulties, before considered fatal to them, have been overcome. They are still far from perfect, though it may yet be expected that accumulators or secondary batteries will play the most important part in all extended systems of electric lighting, transmission of power, and the satisfactory solution of the utilization of wind and water power.

The earliest form of accumulator was a voltameter worked backwards, and was first observed in 1801 by the French chemist, Gautherot. Two years later Ritter, in Germany, carried out a number of experiments in the same direction, and endeavoured to utilize the reaction; he employed for this purpose two plates of gold, separated from each other by flannel kept moistened with acid, and charged by an ordinary Volta's pile. If two pieces of platinum be immersed in dilute sulphuric acid and connected to the two poles of a battery, so that a current be sent through them,

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[1] This communication was read and discussed at a meeting of the Students on the 16th of January, 1885.

the liquid will be decomposed, hydrogen being given off at one plate and oxygen at the other. If then the battery is disconnected and the plates circuited through a galvanometer, it will be seen that they give out a current in the opposite direction to the charging current.

Becquerel first pointed out the real cause of the returned current, upsetting the original theory that the plates absorbed the current during the charging, and gave it up again during the discharge. He showed that the returned current was not due to the storage of electricity, but to the presence of substances having chemical affinities for each other, derived from the decomposition going on during the charge.

If two sheets of ordinary lead be placed in dilute sulphuric acid, and a current be sent through them, a dark brown deposit will form upon the plate connected to the positive pole of the charging battery, due to the formation of peroxide of lead on the surface of that plate, whilst the other will be reduced slightly to spongy lead. Upon disconnecting these plates from the charging source, and circuiting them through a galvanometer, a current will flow from the brown or peroxidized plate to the other reduced plate.

The result is the reduction of the peroxide of lead on the one plate to oxide, and then to sulphate of lead from the presence of the sulphuric acid in the solution; and of the spongy lead to sulphate of lead. Upon recharging, the anode or brown plate, attached to the positive pole of the charging source, will again become peroxidized, and the cathode or other plate reduced to spongy lead. The sulphate of lead will thus disappear from both plates. The plates are thus continually oxidized and deoxidized as they are charged and discharged.

This is a secondary battery in its simplest form, and all accumulators are based upon this principle. Lead has proved by far the best metal for the purpose, because it forms an almost insoluble oxide; a few other metals are nearly insoluble, but lead has the advantage. It is better than silver or manganese for the reason that its oxide is less soluble than either of them.

The initial electromotive force of a freshly prepared cell when charged is 2·25 volts, but this drops after the first few minutes of the discharge to a little less than 2 volts, which may be taken as the normal electromotive force of a cell made up of peroxide of lead, spongy lead and dilute sulphuric acid. The constancy of the electromotive force of a cell varies considerably with the rate of discharge. If it is run down, or discharged, at a very rapid rate it falls off very quickly; whereas if only a small current be taken

out the electromotive force will remain constant for a long time, though the loss on the negative plate or anode from local action will be greater. The strength of the electrolyte or solution varies considerably during the charging or discharging of the cell. When the cell is fully charged the solution is strongest, and when discharged weakest. From this it follows that the internal resistance of a battery is lowest when the electromotive force is at its highest, and the converse. Dr. Frankland has endeavoured to utilize this change in the specific gravity of the solution, to indicate the condition of the cell, and has found that a change of 0·005 in the specific gravity was equal to a storage of 20 ampere-hours. This method of determining the state of the cell does not in practice give very good results, on account of the difficulty of getting the solution in the cell to circulate freely, so as to be of the same density throughout.

The first practicable form of accumulator was that of Planté, made in 1860. He took two sheets of lead, and, placing them in dilute sulphuric acid, passed a current through them for some time. Then disconnecting the cell from the charging source, he discharged it, and again charged it, but this time in a reverse direction; so that the lead plate, formerly connected to the positive pole of the charging source, was this time connected to the negative pole. A number of charges and discharges were thus alternately effected until the plates were rendered sufficiently porous to give a satisfactory storage capacity. Planté found that it was necessary to continue this process for some months before a battery was fit for use. Of course when the battery was used the current was sent through it always in the same direction. The reverse charges were only employed to "form" the plates, or render them sufficiently porous to hold a charge. Unfortunately this form of cell, simple as it is, does not store much electrical energy, except when very thin plates are employed, and these soon become brittle and liable to fall to pieces through being entirely converted into peroxide of lead and thereby losing their stability.

According to Géraldy a Planté cell containing 1·445 kilogram of lead is capable of storing 4,983 kilogrammetres of energy, or 11,329 foot-pounds per lb. of lead. De Meritens modified the Planté cell by making the plates out of a number of thin sheets of lead laid one upon the top of the other, and soldering their edges together, thus obtaining plates composed of a number of layers of thin sheet lead.

Kabath again modified this by taking long thin strips of lead

which he corrugated by passing them through grooved rollers, and then interleaving them with plain strips, or ribbons of lead, folding them backwards and forwards, until a plate was formed of the required size. The drawback to this form is that the lead used is of necessity very thin, and thus soon breaks down and renders the cell useless. In both these cases the same tedious process of forming as in the Planté cell has to be gone through.

In 1880 Faure devised the plan of pasting red lead, or minium, upon plates of plain lead; this paste was rapidly peroxidized and reduced in one charge, thus overcoming and doing away with the long process of forming the Planté plates. The paste had to be held on the plates by wrapping them in flannel or some such porous material. This increased the internal resistance of the cell, and after a time the flannel began to get rotten and fall off, causing the cell to fail. A much higher storage capacity, however, was obtained, it being 18,000 foot-pounds per lb. of lead and minium. Many improvements have been introduced by Messrs. Sellon and Volckmar, culminating in the form now manufactured by the Electrical Power and Storage Company, which consists of grids of cast-lead with holes from $\frac{1}{4}$ to $\frac{3}{8}$ inch square.

The grid used for the anode is made thicker than that for the cathode. These castings are filled with a paste of minium and dilute sulphuric acid. After being dried they are placed in long troughs, filled with dilute sulphuric acid, and a current is sent through them to form them. The amount of current necessary to convert 1 lb. of minium to peroxide is 70 ampere-hours, and 140 ampere-hours to reduce it to metallic lead. But as it only needs 110 ampere-hours to reduce 1 lb. of litharge, this is generally employed for the cathode plate. After the current has been sent through the plates, they are taken out, washed, and stacked until required for use, when they are mounted in their respective cells, and employed for lighting or other purposes. No felt is put between these plates; they are separated from each other by india-rubber bands, pieces of wood, or some similar device.

The storage capacity of this cell is considerably higher than that of the Faure type, being 48,000 foot-pounds per lb. of lead. But since the storage capacity of a theoretically perfect secondary battery is 360,000 foot-pounds per lb. of lead, even the best cell falls far short of this. The figures in Table I. against Sellon-Volckmar are the results obtained from cells specially constructed for driving electric launches, tramcars, &c. Those employed ordinarily for lighting-purposes yield about 36,000 foot-pounds per lb. of lead.

TABLE I.—STORAGE-CAPACITY of the various SECONDARY BATTERIES as REGARDS RATIO of WORK to WEIGHT.

Name.	Storage Capacity in foot-lbs. per lb. of Lead.	Percentage of Efficiency.
Theoretically perfect cell	360,000	100·00
Sellon-Volckmar . .	48,000	13·13
Crompton-Fitzgerald .	24,000	6·66
Faure	18,000	4·99
Planté	12,000	3·33

It has been proposed by Mr. Fitzgerald to substitute carbon for the lead employed for establishing contact with the active material of the cathodes, where oxides of lead are used, and also to protect parts of the anodes by means of some insulating material, so as to arrest the process of peroxidation over the whole of the plates, and thus always to preserve a good contact throughout the anode. A large number of experiments have been carried out in this direction. The best results obtained were from a battery made up of cathodes composed of minium and carbon fragments, held in a punctured lead envelope, and anodes composed of spongy or finely-divided lead, also held in a punctured lead envelope, and protected by a network of insulating material, generally known under the name of Prout's glue. This form had a storage-capacity of 24,000 foot-pounds per lb. of lead. Messrs. Beaumont and Biggs' battery is made up of plates of compressed spongy lead. The lead is obtained in this state by precipitation from a solution of acetate, or sugar of lead, in which solution is placed a plate of zinc. Lead, in a state of very fine subdivision, is deposited upon the zinc, from which it is scraped off, put into moulds, and subjected to hydraulic pressure. By this means plates of great porosity are obtained, which should have as high a storage-capacity as any known form of battery. Of the numerous batteries in the market, nearly all are modifications of the well-known Planté type, which seems to be the best form for durability, if not for storage-capacity; and the "life" of a battery is of far more importance than its storage-capacity per lb. weight. The most notable battery of this class, and one coming prominently into notice, is manufactured by the Wolverhampton Electric Light Co., called the Elwell-Parker accumulator. The plates of this battery are made of sheet-lead

only, but before being formed they are immersed in a strong solution of nitric acid, which attacks the surface of the lead, and honeycombs it to a certain extent. Thus, according to Planté, who first patented this process in 1881, the long process of forming is to a great extent done away with. There seems, however, to be considerable doubt whether this is the case, or if the nitric acid simply dissolves the lead. In all probability the acid attacks the impurities in the lead, and thus prepares the plate in the best possible manner to receive the current. Another battery is the B. T. K., so called from the names of the inventors, Messrs. Beeman, Taylor, and King. This is a modification of the Kabath accumulator, consisting of plates made of alternate corrugated and plain strips of lead, wound round and round upon themselves. Batteries of this description are being largely used in the district-lighting at Colchester.

An improvement by Dr. Frankland is claimed upon the Sellon-Volckmar type of battery, by hardening the paste of minium, or other oxide of lead used in the plates, by immersing the plates in solutions of sulphuric acid of various densities during different periods. He also claims for the plates the capacity of receiving a higher rate of charge. This hardening mixture may be cast into plates or cylinders of any desired form or size. There are also many other batteries of the Planté type by various inventors. Mr. Joel has patented a plate having a considerable storage-capacity. He makes the plates of lead-wool, or perhaps more properly speaking, lead-fibre, mixed with minium, and then pressed upon a cast-lead plate which acts both as a conductor and support.

A battery differing in many ways from those already mentioned was that proposed by Sutton. He took two plates, one of lead and the other of copper, and immersed them in a solution of sulphate of copper. The lead plate became peroxidized, and the copper was alternately dissolved and deposited from the solution of sulphate of copper. This battery, though giving good results upon a small scale, failed when used to a large extent. The electromotive force is much lower than that of a cell composed of lead only.

The advantages of accumulators made after the Planté type over those of the Faure type are that they afford a far higher rate of discharge. This property is invaluable for many purposes, as, for instance, where numerous lamps are required to be run for only a short time. But then again accumulators of the Faure type take in a higher rate of charge than the Planté, because they have a

greater thickness of working material, and also store a larger amount of electrical energy in a given weight.

The durability, or life, of a secondary battery, has never been satisfactorily settled. Manufacturers assert that their accumulators will last for a number of years, but this has not yet been proved. Those of the Sellon-Volckmar type, cannot, the Author believes, be depended upon to last more than five or six months at the outside, when they are worked regularly every day up to their full capacity. But when overcharged continuously, or otherwise improperly used, a few days will often suffice to put them out of order.

The Planté accumulator should last longer than this, but it must be borne in mind that when this battery has arrived at its maximum of efficiency, it is on the point of falling to pieces. Where water- or steam-power is available, a rough, but serviceable battery may be made by taking sheets of thick lead, cutting them into plates of any required size, and mounting them in tanks filled with dilute sulphuric acid. Of course during the first few charges the storage-capacity will be very small, but this will improve every day; at the same time the cost of forming them is next to nothing. Eventually it will prove to be a most efficient battery.

The first and most important point in setting up a secondary battery is to carefully insulate the cells from each other, and from any moisture. This is best effected by arranging them on wooden shelves raised about 8 inches off the floor, and at an equal distance from the walls. The boxes should be left with a space of at least an inch between them, and wherever possible placed in single rows and not upon shelves one on the top of the other, so that free access may be had to each box. In large installations the cells are often of considerable size weighing from 5 to 6 cwt. each, thus rendering it extremely difficult to move them. For these reasons they should be so arranged that, once put up, they can be easily got at for repair without being removed. The importance of keeping the cells perfectly free from moisture can hardly be overrated. If they should be placed upon a damp floor, or in any position where moisture can get to them, there will be a considerable leakage of electricity, the cells will rapidly run down (*i.e.*, become discharged), and will be in all probability condemned as unworkable and useless.

All secondary batteries, when first set up, should be tested for insulation. This may easily be done by connecting one pole of the battery (after it has been charged) to one terminal of an ordinary galvanometer, and the other terminal of the galvano-

meter to earth. The best way to obtain a good earth is to connect the wire to a water- or gas-pipe; or if neither of these should be available, to drive a piece of iron into the ground and make a connection in that way. If the needle is deflected it indicates leakage, which should at once be remedied. The leakage will in all probability be found to arise from an escape of the solution from one of the cells, the place where they are standing being damp, or one of the leads "making earth." The poles of the cells should be connected together by stout bars of metal. It is inadvisable to use copper on the positive pole of a cell on account of the rapidity with which it corrodes. Plain lead connections or a mixture of lead and antimony are the most trustworthy. The positive pole of one cell is joined to the negative of the next and so on all through the series. Then the positive pole of the dynamo is connected to the last positive of the battery, and the negative to the negative. The contacts must be properly made between each cell, as a bad contact will produce a great deal of heat in the cells, thereby introducing resistance into the circuit and reducing materially the rate of charge or discharge. Care should be taken not to charge the battery at too rapid a rate, and if at any time during the charging the cells become warm, the charging should be stopped, and the battery allowed to cool down. The heating of the plates causes them to buckle, often resulting in the short circuiting of the cell, and thus putting it out of use until the defect has been remedied.

During the charging, and also whilst they are at rest, it is advisable to test the cells from time to time. This may be readily done by taking a short length of stout wire, holding one end upon one pole of the cell to be tested, and striking the opposite pole with the other end of the wire. If the cell is in good condition it should give a bright crip spark. If it gives no spark at all it shows that there is a short circuit in the cell, arising in all likelihood from two of the plates touching each other, or from a small piece of some conducting substance having fallen down between the plates. This should be at once remedied, otherwise the cell should be cut out from the circuit and taken to pieces. It is very important when working batteries to keep all the cells in as even a condition as possible. For if a cell be empty, or is discharged before the others, it will then become recharged in the reverse direction, and thus set up an opposing electro-motive force to the rest of the battery, besides there is the risk of spoiling that particular cell. Keeping all the cells in the same condition is best effected by observing them when charging, and

cutting out of the circuit all those cells that give off gas freely, and continuing to charge the others until they are all fully charged. If this is done about once in two months, the working efficiency of the battery will be maintained at a very high point. Of course this entails extra labour, but the Author contends that secondary batteries do, and always will, require skilled supervision. Care must be taken not to cut out too many cells whilst charging the battery without introducing a corresponding resistance, or the dynamo will be burnt.

The ordinary strength of the electrolyte is 1 part of sulphuric acid to 9 parts of water, or of a specific gravity of 1·2; that of sulphuric acid being 1·84. The water should be as pure as possible. When working a battery, it is necessary to keep all the plates immersed in the electrolyte. If it becomes necessary to add to the electrolyte, to keep the cell full, water only should be used, otherwise the solution will become too strong. When batteries are left out of use for any length of time, it is advisable either to remove the solution, and wash the plates and boxes with water, or else to leave them fully charged. This latter method is perhaps best adopted only when the battery is not to be out of use for very long. It is found that, when batteries are left idle and full of the solution, sulphate of lead will form all over the plates, and have a serious effect upon their future working.

By discharging a cell too rapidly, as much harm can be done to it as by charging it too rapidly.

The best dynamos for charging accumulators are shunt dynamos. Both the series and compound machines are liable to have their poles reversed by the batteries discharging through them, which is likely to arise from the speed of the dynamo decreasing, and thereby having its electromotive force overpowered by that of the battery. This difficulty might be overcome by specially-designed automatic switches. The most economical way is to charge each battery in two series in parallel, though of course, whilst charging them in this manner, no lights can be run at the same time. The circuit should be so arranged that the dynamo is charging the battery in two series in parallel, or in one series with the lamps in parallel, or dynamo, lamps, and battery all in parallel. In order to charge an accumulator, it is necessary to employ a dynamo giving an electromotive force greater than that of the cells, and greater in proportion to the rate of charge required; but as all excess of electromotive force is lost energy, a slow charge is the most economical where time is of little moment.

The uses to which accumulators may be put are almost endless.

They are serviceable for every application of the electric current. Lighting being at present the most in need of them, by employing an accumulator in any installation, the failure of the light should be rendered almost impossible. The chief causes of break-downs are the slipping, or breaking of belts, the heating of the bearings, or some trivial mishap with the engine which may be set right in a few minutes, but which is sufficient to plunge the place lighted into darkness. Now by employing accumulators, if the engine has to be stopped, the batteries immediately come into action, and should run the lights long enough for the necessary repairs to be effected. In nine cases out of ten, the failure of an electric light can be traced to some minor breakage or mishap that can be remedied in half-an-hour or even less; but, of however short duration, a total extinction of the lights must follow when working direct from the dynamo. Again, in almost all factories and workshops where steam-power is used, there is a surplus of from 2 to 4 HP. This surplus, if employed to drive a small dynamo and to charge batteries all day, would be sufficient to run enough glow-lamps to light up the whole of the shops in the evening. Accumulators may also be used advantageously in steadying the light when the dynamo is worked by a gas-engine, or any irregular source of power. The only method of satisfactorily solving the problem of the utilization of water-power is by employing storage batteries, so that the water, instead of running to waste day and night, could be made to store electricity, which in its turn could either be used for motive-power or for ordinary lighting purposes, and be drawn off at will. This applies also to the possibility of utilizing wind-power.

The employment of secondary batteries for driving trains, tram-cars, boats, &c., has been a good deal discussed, but up to the present time, although many costly experiments have been undertaken, no practical work has been done.

The first experimental launch worked by accumulators was that fitted up by the Electrical Power Storage Co., and launched at Millwall in September, 1882. She was 25 feet long, 5 feet beam, with accommodation for about ten passengers. She was driven by two Siemens dynamos of the S D_3 type, coupled in parallel. The current was supplied by forty-five 1 HP. Faure-Sellon-Volckmar cells. The two motors running together absorbed a current of 46 amperes, and developed about 3·75 HP. The weight of each motor was 316 lbs.; that of the countershaft, &c., was 180 lbs.; and the total weight of the accumulators was 2,520 lbs., or 56 lbs. per cell.

The second launch was built by Messrs. Yarrow and Co. of Poplar, and was fitted with all the electrical arrangements by the Electrical Power Storage Co. for the Vienna Exhibition of 1883. She is 40 feet long, 5 feet beam, and will carry about forty passengers. In this boat the motor and batteries are placed under the floor. The motor used is a Siemens D_2 dynamo, which with eighty Faure-Sellon-Volckmar accumulators (the number carried) will develop 7 HP. Its weight is 658 lbs., and the efficiency when tested was 78 per cent. In this boat no gearing is used between the motor and screw-shaft, the former being coupled directly to the latter. The average speed attained was 8 miles per hour. The advantages are that whereas two men are necessary to work a steam-launch, the electric-launch needs but one man to look after it, as he can steer, stop, or regulate the speed at the same time. An electric-launch will also carry more passengers, besides being free from smoke, smell, heat, and noise.

The experiments carried out with tramcars have not yet advanced nearly so far. A trial trip was made on the Gunnersbury and Kew tramway line on the 10th of March, 1883. The experimental car, as in the case of the launch, was fitted up by the Electrical Power Storage Co., and was of the ordinary type used upon the London tramways. It was driven by a Siemens dynamo, designed to work with an electromotive force of 100 volts, and a current of 60 amperes furnished by fifty accumulators placed under the seats of the car. The cells measured 13 inches by 11 inches by 7 inches, and weighed 80 lbs., their total weight being 4,000 lbs. The storage capacity of each cell was 560 ampere-hours. Apart from this experiment, which did not altogether end successfully, the problem of propelling tramcars has not been solved. The same company exhibited a tricycle at the Vienna Exhibition worked by twenty-one small accumulators, and a motor designed by Mr. Reckenzaun of London. This would run for about one hour, and cover about 8 miles in that time. The main reason why electricity has not yet been employed for motive power, for boats and tramcars is, the Author thinks, undoubtedly to be traced to the still imperfect and unsatisfactory state of secondary batteries. When once they have been so far improved as to be looked upon as trustworthy, a great and lasting impetus will certainly be given to the utilization of electricity, for motive power as well as for lighting-purposes.

(*Students' Paper No. 181.*)

Trigonometrical Surveying.[1]

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For some time past the Author's attention has been directed to the various methods of computation adopted on the Ordnance Survey, and having collected such information as should be necessary to explain these computations by means of practical examples, he has been led to make this the subject of the present Paper.

No survey of any great extent can be conducted without the aid of trigonometrical principles, and although in this country the National Survey has in a great measure done away with the necessity of making surveys of any very great magnitude, still in the Colonies there is yet a field where the principles may be put into practice.

The computations embrace both spherical and plane trigonometrical principles. It is due to the spheroidal form of the earth that spherical computations occur. As regards the computations of plane triangles, it will be readily understood that it would be impossible to chain every line in the triangulation of a survey; some lines connecting points on opposite sides of rivers, lakes, and channels, and others, points situate on high hills and rugged mountain-tops. Thus it is that recourse must be had to the principles of trigonometry, to determine the distances between remote objects with accuracy. From this it may be inferred that the foundation of trigonometrical surveying depends on the computation of the several triangles embracing the survey. To solve any triangle, at least one side and two angles must be given, and on these elements the subsequent operations are based. In order to obtain one side, a "base line" is accurately measured, and from each end of it angles are observed to the apex of the triangle of which it forms the base. This triangle can then be solved; and by using each of the sides of this triangle as bases, other points can be dealt with in a similar manner, and their respective positions determined.

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[1] This communication was read and discussed at a meeting of the Students on the 5th of December, 1884.

A trigonometrical survey may be defined as being a network of triangles of different magnitudes, dependent on a very accurately-measured base line forming a side of one or more triangles, whose angles are obtained by theodolite observations, and the entire system computed from these data.

It would be a difficult matter to conduct a large survey with accuracy by commencing at any one place, laying out a system of small triangles, as for detail work, and building out therefrom, until the entire area to be surveyed had been included; as any error at the commencement, however small, would gradually be developed as the survey extended, and there would be no means of destroying it; whereas an error made under the ordinary system is confined to its own triangulation, and does not expand, but is gradually destroyed.

A story is told of how a schoolmaster in a country village, well versed as he thought in the principles of surveying, commenced to survey the parish in which he lived. He measured each field separately, but when the survey was plotted, there was a field missing in the centre of the plan. This he could not account for, as he had measured each field most accurately. However, rather than be beaten, he made a "note" in the corner of the plan, giving a sketch of the field as follows: "Note. This field should be shown in the centre of the plan, but there was no room for it." The same kind of thing would occur on a large survey without having recourse to the principles of trigonometry, and instead of one field, possibly whole parishes would be missing.

In order more fully to explain the methods of dealing with each system of triangles, the Author has obtained data of a portion of the Ordnance Survey, which, being of a practical nature, will be the more interesting. The piece of work selected embraces a portion of South Wales and the County of Cornwall.

The National Survey has been divided into three systems of triangulation :—

(1.) The primary, or great instrument work.
(2.) The secondary triangulation.
(3.) The minor, or parish work.

The accompanying map (Plate 5) shows the position of the several stations.

It will not be out of place to explain how the stations are selected, and the methods of observing from them.

For the great instrument work, high hills, elevated positions, and prominent points are selected.

For the secondary and parish work, a person called a "poler" is

sent out to select stations such as church-towers, prominent buildings, and various localities from which a number of other stations can be conveniently observed. When the poler has decided upon a station, say on the side of a hill, or in a field, he there erects a pole from 8 to 10 feet long. A hole 18 inches deep is usually dug in the ground, and a flat stone put in it. A small hole is made in the stone, and a nail driven through the bottom of the pole fits into the hole when the pole is erected.

The pole is then plumbed and secured by stays on three sides. Two vanes of timber, 6 inches wide, nailed near the top of the pole and at right angles to one-another, serve for the intersection of the cross hairs in the theodolites. A rough diagram of the selected stations is then made by the poler for the guidance of the "observer," who next goes out to take observations. He is accompanied by an assistant called his "booker," whose duty it is to record the observations as they are read by the observer. Having fixed the theodolite over a station, it is adjusted in all its movements; some one station or a prominent object is selected as a "referring object" (R.O.), and this is first observed and the reading booked. The telescope is then directed to the second, third, and following stations, and the readings are noted.

To understand the details of these observations, those recorded in Table I taken with a 12-inch theodolite at Docking Church Tower, one of the stations on the Ordnance Survey, may be referred to. Being unable to obtain the details of the great instrument work, the Author had to content himself with the present example, which, as regards explaining the principles of the work, will serve the same purpose.

The lower limb being clamped and the telescope directed to the R. O., which in the example is the trigonometrical pole (T. P.), at Brancaster Farm, the reading was 173° 53′, 30″ A., 39″ B., 39″ C. On the 12-inch theodolites there are three verniers reading to single seconds, as in the example. The lower limb still being clamped, the telescope was next directed to the T. P. Brancaster Field House, and then to Manor Farm and so on. It will be seen on inspecting Table I that at the termination of this series of observations the R. O. was re-observed, a different value resulting in the seconds, at once showing that the instrument has been wrongly read or that it is badly graduated.

The error possibly belongs to both; but however careful and skilful an observer may be, it is nevertheless invariably the case that different values result in the vernier readings. This state of things at once shows the necessity of having more than one vernier,

and consequently their number should be in proportion to the diameter of the instrument employed. This series of observations closes what is termed Arc No. 1. For a still closer approximation to the values of the observations a second series is taken as follows:—

The lower limb, which up to this stage of the operation had been clamped, is now unclamped and turned through any arc at the will of the observer, and re-clamped in a new position. Each of the stations is again observed as for Arc No. 1. This second series is called Arc No. 2. In the example for Arc No. 2, the reading of the R. O. is 210° 34′ 50·3″, and the difference between this and the reading of the R. O. in Arc. No. 1 represents the angle through which the instrument was turned for the first approximation to the values of Arc No. 1. This second series having been observed, the lower limb is again unclamped and turned through any arc, and being reclamped, the observations for Arc No. 3 are taken.

In this manner a series of arcs is taken at each station throughout the survey. The distances being large between the primary and secondary stations, the observations are affected in no small degree by the varying light and atmospheric changes which are constantly taking place; and in order to minimize the probability of errors entering into the observations, the above method has been adopted, by which a mean value of each observation is obtained, thus reducing the errors to a minimum. This method of taking observations is carried out at each station, and, although a very laborious and costly one, still the results obtained are the most satisfactory, and more than balance the expenditure of time and money in obtaining them; as without perfectly satisfactory results, the survey must, on account of its magnitude, be liable to large and frequent errors. The field-notes are next dealt with as follows:—

The mean value of the seconds in the vernier-readings is calculated in the ordinary way, and inserted in the column headed "Mean of Seconds."

Referring to the Appendix, Table I, Arc No. 1, two values result for the R. O., as there are two observations, one at the commencement and the other at the termination of the arc. Of these two means the mean is again taken, and the result (39·2″) inserted as shown.

In this manner the values of the seconds are calculated for each arc and tabulated.

The "readings" are now reduced to the south meridian line

(S. M.), and are then termed "bearings." The south pole is assumed to be 00, and the north 180°, the bearings being read the same way as the hands of a clock revolve. By an independent set of observations, taken at "Docking Church Tower" (Table I), the R. O. was found to bear 183° 34′ 40·0″ with the S.M. line, so that the R. O. lies between the N. and E. of the meridian through the station. This bearing is inserted in the column "Reading in Abstract," opposite the R. O.

Now the mean value of R. O. in Arc No. 1 is 173° 53′ 39·2″, and the difference between this reading and the S. M. bearing is 9° 41′ 0·8″; so that, in order to reduce the other observations to the S. M., the difference for Arc No. 1 must be added to each of them. The reading of the R. O. in Arc No. 2 is 210° 34′ 53·5″, and the S. M. bearing being 183° 34′ 40·0″, the difference, 27° 0′ 13·5″, must be taken from each of the observations in Arc No. 2, so that they may be put on the meridian. Each arc is dealt with in this manner by applying plus and minus values of the differences between the R. O. observations and the south meridian bearing.

The "bearings" must next be abstracted, and they form Table II, which shows the manner of dealing with the seconds in each arc. On referring to Table II the mean value of the seconds in each arc is taken and inserted as shown. The next step is to calculate the "reciprocal of the weight" of each observation, a quantity applied to the computations of the triangles, as will be shown at a later stage of this Paper.

The rule for obtaining this quantity is:—

"Twice the sum of the squares of the errors of observation, divided by the square of the number of observations, is equal to the reciprocal of the weight of the observations."

The "error of an observation" is the difference between that observation and the mean of the observations of which it is one. The "final means" are next abstracted, and with the degrees and minutes form the observation table. In this manner Table III of Spherical Bearings has been constructed.

It will now be shown in what way the "Computation Diagram" is constructed, referring to that portion of the primary triangulation selected as an example. The base taken is from Precelly to Cradle. This distance is plotted on a piece of paper to a convenient scale by first fixing one of the ends as Precelly, and having put the protractor over the station (assuming the top of the paper to be north), lay off the bearing of Cradle from this station by looking up in Table III "at Precelly," which will be found is 268° 59′ 42·98″. Thus Cradle bears nearly due east of

Precelly, and along this bearing plot the given distance between the two points. The position of Cradle is now determined. As the protractor is "at Precelly," lay off all the bearings of the stations observed from it, namely Dunkerry, Paracombe, Highwilhays, and Lundy Island, by means of thin pencil lines. Along these lines write also in pencil the name of the station to which each line corresponds.

Next remove the protractor to Cradle, retaining the same north point, and lay off from it all the stations it observes. On inspecting Table III, it will be found that Cradle observes Dunkerry, Paracombe, Precelly, and Mendip. Now as Precelly also observed Dunkerry and Paracombe, these two points are fixed. Then removing the protractor to one of these, say Paracombe, from it lay off as before the several stations it observes.

This time the positions of other points will be obtained by intersections. The object of this diagram being merely for computation purposes, the bearings are only laid off to the nearest minute, so that the several bearings from different stations may not intersect exactly in one point; but the mean intersection will determine approximately the position of a station. Having pencilled in all the bearings, and determined the position of each station, a small ink circle should be described about each, and the name written in ink. It is next advisable to clean the paper, leaving nothing but the stations with their respective names.

Referring again to Table III, and commencing with "at Precelly," draw ink-lines from it towards each station it observes, but not quite up to the stations. Then taking "at Cradle" next, from it draw lines in the same manner. Now as Precelly observes Cradle, and is reciprocally observed, the result is a full ink-line between them. Similarly for the other stations, the rule being that "if one station observes another, and is reciprocally observed, a full ink-line results; but if not, then an ink-line is drawn from the observing station in the direction of, but not quite up to, the station observed. The object in drawing ink-lines as above, is to show, on inspecting the diagram, which angles must be inferred in the solution of the triangles. This completes the construction of the "Computation Diagram;" the next proceeding being to select the triangles for computation. In describing a triangle, it is usual to first write down the stations at each end of the base.

Precelly to Cradle being the given base, with this a commencement is made as the first side of triangle No. 1.

Table IV shows the triangles adopted for this triangulation, but

practice alone can ensure proficiency in the selection of triangles, the main feature being to get proofs on the several sides from different triangles.

To obtain the angles of these triangles refer to Table III. Commencing with triangle No. 1, to find the angle at "Precelly" between Cradle and Paracombe, look up "at Precelly," and it will be seen that Cradle and Paracombe bear respectively 268° 59′ 42·98″ and 323° 8′ 49·46″. The difference between these two bearings—54° 9′ 6·48″—is naturally the angle at Precelly. To find the angle at "Cradle," between Precelly and Paracombe, look up "at Cradle," and the difference between the bearings of Precelly and Paracombe, namely, 59° 22′ 27·11″ is the angle at Cradle. For the remaining angle at "Paracombe," the difference between the bearings of Precelly and Cradle, namely, 66° 28′ 48·86″, is the angle at Paracombe. The angles for triangle No. 2 are obtained in a similar manner.

In triangle No. 3, however, to obtain the angle at "Cradle," between Dunkerry and Mendip, the bearing of Dunkerry is 18° 59′ 23·79″, and that of Mendip 332° 18′ 18·99″. These bearings being on opposite sides of the S.M. through the station, it is necessary to deduct the bearing of Mendip from the S.M. (360°), and the difference added to the bearing of Dunkerry, gives the angle 46° 41′ 4·80″ at "Cradle."

The angles of the following twelve triangles are obtained in precisely the same manner; but, in the next triangle, No. 16, the first and third angles are obtained as above, and as "at Pillesden" there is no bearing for "Ryders Hill," the supplementary angle must be taken. The above examples serve to explain the methods of obtaining the various angles. Having inserted the several angles in the column headed "angles observed," sum the angles in each triangle, and put the result as shown. In No. 21, Primary Triangles are given with the solutions in detail.

Before proceeding with the practical portion of the computations, it will perhaps be as well to give the formulas from which they are obtained.

As the question involved is the Primary Triangulation, the distances being large will be affected by the spheroidal form of the earth. The sides of these triangles will represent arcs on the spheroid, the angles being spherical angles. The first correction is to reduce the spherical angles to plane angles, and solve the triangles as plane triangles. The spherical excess (S.E.), which enters into large spherical triangles, is the excess of the sum of

the observed angles above 180°, its value depending on the area and latitude of the triangles.

The spherical excess on a triangle is obtained from the formula—

$$\text{S. E.} = \frac{c \cdot a \cdot \sin \text{B}}{2\, \nu^2 \sin 1''}$$

where (c) is the given base, (a) a side of the triangle obtained approximately, and (B) the angle between (a) and (c). $2\nu^2 \sin 1''$ is a constant obtained from Table V, where $\frac{1}{\text{E}_0}$ represents its arithmetical complement, (ν) being the radius of the sphere which varies with the latitude in which the triangle is situated.

For the solution of the triangles when the base and the three angles are given the ordinary sine-rule is used—

$$\frac{\text{Sin A}}{a} = \frac{\sin \text{B}}{b} = \frac{\sin \text{C}}{c}$$

when if c = base

$$a = \frac{c \sin \text{A}}{\sin \text{C}},\ b = \frac{c \sin \text{B}}{\sin \text{C}}$$

The denominators of the last two equations may be transformed from negative into positive logarithmic values by using their arithmetical complements.

Proceeding to compute the spherical excess on triangle No. 1.

To obtain the value of (a)—

Log a	= log c + L sin A − L sin C	
Log c	= 5·5712951	base Precelly—Cradle
L sin A . . .	= 9·9087967	angle at Precelly
Arith. comp. L sin C	= 0·0376663	„ „ Paracombe
Log a . .	= 5·5177581	= Cradle—Paracombe.

It may here be remarked, that for the computation of the spherical excess it is unnecessary to employ more than the first five decimal places, and the log sines need only be taken out for the degrees and minutes, omitting the seconds.

For the final computations for the sides of the triangles, the utmost accuracy is necessary, so much so that when the "angles for computation" have been obtained, the log sines, &c., must be calculated to two places of decimals in the seconds, otherwise the solutions would be very unsatisfactory.

Now by formula for spherical excess,

$$
\begin{aligned}
\text{Log } c &= 5\cdot57129 \text{ (base) Precelly—Cradle}\\
\text{Log } a &= 5\cdot51775 \text{ Cradle—Paracombe}\\
\text{L sin B} &= 9\cdot93476 \text{ L sin } 59^\circ\ 22'\ 27''\\
\text{Log } \frac{1}{E'} &= 0\cdot37158 \text{ constant from Table V. for latitude } 50^\circ\ 20'\\
& \overline{1\cdot39538} = \text{log of seconds.}
\end{aligned}
$$

Natural number corresponding to log of seconds = 24·85″ = S. E.

This quantity is the true excess of the sum of the angles of Δ No. 1 above 180°

Now the sum of the observed angles of Δ No. 1	=	180°	0	22·45″
180° + (S. E.)	=	180	0	24·85
Difference	=	0	0	2·40

This difference is termed the error on the triangle.

The sum of the observed angles being less than 180° + (S. E.), the error is negative—

$$\therefore \text{error} = -\,2\cdot40''$$

Having now determined the error on the triangle, the next step is to apportion the spherical excess to the three angles in proportion to the weights. The spherical excess is a negative quantity, and $\frac{1}{3}$ (one-third) is applied to each observed angle as below.

$$\tfrac{1}{3}\text{ S. E.} = -\,8\cdot28,\ -\,8\cdot28,\ -\,8\cdot29.$$

Had the spherical excess been a multiple of three, each angle would have had the same amount, but it is usual when such is not the case to give the worst angle the greatest value. The best angle in a triangle is that nearest 60°, since 3 × 60° = 180°.

In the earlier part of this Paper, the rule for obtaining the "reciprocal of the weight" of an observation was given; it will now be shown how the weight of an angle is obtained, and the manner of applying the values in conjunction with the spherical excess, so that the sum of the observed angles in each triangle shall equal 180°. These new angles will then be the "angles for computation."

In Table III there will be found for Δ No. 1 "at Precelly," and opposite each of the stations observed, the reciprocal of the weight of each bearing. In order to obtain the value of the weight of

the angle at Precelly Δ No. 1, sum the reciprocals of the weights of the bearings of Cradle and Paracombe.

Thus $0 \cdot 24 + 0 \cdot 25 = 0 \cdot 49$. Weight of angle at Precelly. This value must now be inserted in column "Weights," opposite Precelly. In like manner, for the value of the weight of angle at Cradle, take the sum of the reciprocals of the weights of the bearings at Precelly and Paracombe = $0 \cdot 52$; and for Paracombe the sum of the reciprocals of the weights of bearings at Precelly and Cradle = $0 \cdot 98$. Insert each of these values as shown, together with their sum ($1 \cdot 99$). This latter value is now employed with the error $-$ ($2 \cdot 40''$) to correct each angle in proportion to the weights.

It should here be noted that the "proportion of error" on each angle is always of a contrary sign to the error on the triangle. In Δ No. 1, the error being negative, the proportion will be positive.

To obtain this value the following is the proportion for the angle at Precelly—

"Sum of weights" : error on Δ No. 1 : : weight of angle at Precelly : proportion to be applied.

For Precelly—

$$1 \cdot 99 : 2 \cdot 40 :: 0 \cdot 49 : x$$

$$\therefore x = \frac{2 \cdot 40 \times 0 \cdot 49}{1 \cdot 99} = +0 \cdot 59$$

Similarly for Cradle—

$$1 \cdot 99 : 2 \cdot 40 :: 0 \cdot 52 : y$$

$$\therefore y = \frac{2 \cdot 40 \times 0 \cdot 52}{1 \cdot 99} = 0 \cdot 63$$

and for Paracombe—

$$1 \cdot 99 : 2 \cdot 40 :: 0 \cdot 98 : z$$

$$\therefore z = \frac{2 \cdot 40 \times 0 \cdot 98}{1 \cdot 99} = 1 \cdot 18$$

Thus in summary—

Precelly	$x = +0 \cdot 59$
Cradle	$y = +0 \cdot 63$
Paracombe	$z = +1 \cdot 18$
$\therefore (x + y + z)$	$= 2 \cdot 40$

As previously stated, the spherical excess is always a negative

quantity, and the proportion of error on Δ No. 1 being positive, for Precelly—

$$\begin{aligned} \tfrac{1}{3}\,\text{S. E.} &= -\ 8{\cdot}28 \\ x &= +\ 0{\cdot}59 \text{ prop. of error} \\ \hline \therefore x' &= -\ 7{\cdot}69 \left\{\begin{array}{l}\text{correction to be applied to observed} \\ \text{angle at Precelly.}\end{array}\right. \end{aligned}$$

Similarly for Cradle—

$$\begin{aligned} \tfrac{1}{3}\,\text{S. E.} &= -\ 8{\cdot}28 \\ y &= +\ 0{\cdot}63 \\ \hline \therefore y' &= -\ 7{\cdot}65 \text{ ditto for Cradle;} \end{aligned}$$

and lastly for Paracombe—

$$\begin{aligned} \tfrac{1}{3}\,\text{S. E.} &= -\ 8{\cdot}29 \\ z &= +\ 1{\cdot}18 \\ \hline \therefore z' &= -\ 7{\cdot}11 \text{ ditto for Paracombe.} \end{aligned}$$

The corrections for Δ No. 1 are negative, as must naturally be the case, the sum of the observed angles being greater than 180°.

Thus, to obtain the "angle for computation" at Precelly—

Observed angle	=	54°	9′	6·48″
Correction x'	=			− 7·69″
"Angle for computation"	=	54°	8′	58·79″

For Cradle—

Observed angle	=	59°	22′	27·11″
Correction y'	=			− 7·65″
"Angle for computation"	=	59°	22′	19·46″

Lastly, for Paracombe—

Observed angle	=	66°	28′	48·86″
Correction z'	=			− 7·11″
"Angle for computation"	=	66°	28′	41·75″

The new angles, being the "angles for computation," must be tabulated under that head; their sums = 180° 0′ 0″. The angles are now plane angles, and not spherical as formerly; the above method of reducing the angles is due to Legendre, and although not perfectly accurate, it is sufficiently so for all practical purposes, and it is possible to obtain the lengths of the sides of the

triangles in spheroidal arcs expressed in feet, instead of in seconds, of a great circle of the earth, as would have been the case had the triangle been solved by reducing the spherical angles to the angles formed by the chords.

Being in possession of the true angles, find the log sine of each, and insert the results in column headed "Calculation." For the great instrument work it is necessary to take out the log sines to two places of decimals in the seconds. The Author used "Bagay's Logarithms" for the triangulation under consideration. These logarithms are calculated to seven places of decimals, and give by inspection the logs of single seconds, greatly facilitating the work.

Δ No. 1, to obtain the log sine of 54° 8′ 58·79."

By Table—

L. sin 54° 8′ 58″	= 9·9087784
Difference for 1″	= 0·0000015
∴ Difference for 0·79″	= 0·0000012

But as an angle increases from 0° to 90°, so does its sine; therefore 0·0000012 must be added to L. sin 54° 8′ 58″ to obtain L. sin 54° 8′ 58·79″ = 9·9087796. Insert this value in column "Calculation," opposite Precelly. The log sines of the other two angles in this triangle are obtained in the same manner; but as the latter angle is negative in the formula, take its arithmetical complement or difference from 10, and the result 0·0376740 becomes positive.

To obtain the side (a) Cradle to Paracombe, by formula

$$a = \frac{c \sin \mathrm{A}}{\sin \mathrm{C}}.$$

Base log c	= 5·5712951	
L. sin 54° 8′ 58·79″ . .	= 9·9087796	= L. sin A.
L. sin 66° 28′ 41·75″ . .	= 0·0376740	= {arithmetical complement L. sin C.
Sum = log a	= 5·5177487	= {log distance between Cradle and Paracombe.

For log distance between Precelly and Paracombe (b)—

Base log c	= 5·5712951	
L. sin 59° 22′ 19·46″ . .	= 9·9347478	= L. sin B.
L. sin 66° 28′ 41·75″ . .	= 0·0376740	= {arithmetical complement L. sin C.
Sum = log b	= 5·5437169	= {log distance between Precelly and Paracombe.

This completes the solution of Δ No. 1. The log distances of the sides of Δ Nos. 2 and 3 are similarly computed.

The base in Δ No. 2 is Precelly—Cradle as for Δ No. 1; but the base for Δ No. 3 is obtained from Δ No. 2 Cradle to Dunkerry. When the side of a triangle is used as a base, the word "used" should be written against it.

After a triangle has been solved, if any of the sides are proofs on other triangles, proof numbers should be written in the margin as in Table IV, so that in abstracting the log distances no difficulty may be experienced.

Before proceeding to Δ No. 4, it will be necessary to make a few remarks on Δs Nos. 2 and 3. In Δ No. 2 (Table IV) there is no "error" on the Δ; thus all that is required to be done, after ascertaining the spherical excess, is to deduct $\frac{1}{3}$ spherical excess from each of the observed angles to obtain the angles for computation. In Δ No. 3 the error is positive, and therefore the apportionment of error is negative. The spherical excess being negative the sum will be negative. In the first three Δs none of the individual angles exceeded 90°, but in Δ No. 4 the angle at Lundy Island = 93° 21′ 6·07″. Now sin 93° 21′ 6·07″ = cos 3° 21′ 6·07″, therefore for this angle find

$$L \cos 3° 21' 6{\cdot}07'',$$

and insert the arithmetical complement as before.

In obtaining the log of the decimal part of the seconds (0·07″), the log value must be taken from the log cosine of 3° 21′ 6·00″ to get L. cos 3° 21′ 6·07″, as the cosine diminishes when the angle increases from 0° to 90°. These four triangles serve to explain the method of solving triangles when all the angles are given.

It frequently happens that every angle in a triangle is not observed, but two at least must be, the third being a "supplementary angle." Δ No. 16 is an example, the angle at Pillesden being supplementary. One-third (S. E.) is only applied to the observed angles, the whole error being assumed on the supplementary angle. The log distances should next be abstracted, and the mean values of the several sides form the "Distance List," completing the solution of the triangles.

Passing on to the Secondary Triangulation, which is connected to the Great Instrument Work by observations with a 12-inch theodolite, the same methods are pursued as for that triangulation, except that, as the sides of the secondary triangles are much

smaller, the spherical excess does not enter into the calculations, and the triangles are solved in the ordinary way.

Finally the Secondary Triangulation is broken up into the Parish or Minor Work, and the entire system computed. On the Ordnance Survey for the Primary Triangulation, 3-feet, 2-feet, and 18-inch theodolites are used; for the Secondary, 12-inch, and for the Parish work 7-inch theodolites.

The average length of the sides of the Primary Triangulation of the United Kingdom is 35 miles; of the Secondary, 5 miles; and the sides of the Minor triangles vary from 1 mile to 1½ mile. Next commences the ordinary chain surveying, comprising the detail work. One or more of the minor triangles is allotted to each surveyor. The chained distances are compared with the computed ones, and if found not to agree within certain limits, the lines are re-measured, the surveyor being in ignorance of the computed lengths. In order to show how accurately the main triangulation of the Ordnance Survey has been conducted, it may be mentioned that in 1826–27 a base line was measured on the shores of Lough Foyle by means of General Colby's compensated bars, which were designed to nullify their expansion and contraction due to variation of temperature; and in 1849 the old base on the Salisbury Plain was re-measured with the same apparatus. The length of the Salisbury base is 6·97 miles, and of that of Lough Foyle 7·89 miles. The length of the Lough Foyle base was computed by a triangulation carried from the Salisbury base, and the difference between the computed and the measured length of the Lough Foyle base was only 5 inches.

The next and very important part of a trigonometrical survey is plotting the work, which, extending over a large area, must be done on separate sheets. Having adopted a certain scale for plotting, the size of the sheets must be decided upon. A diagram of sheets should then be made, and each sheet numbered.

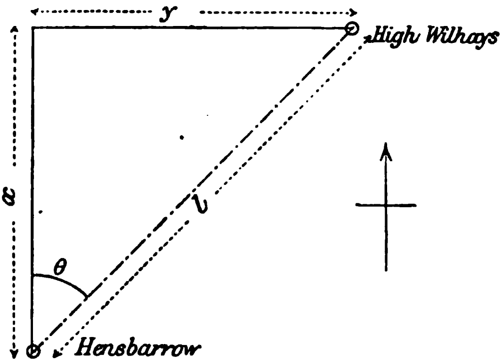
The position of a point is determined by two measurements, namely on and perpendicular to the meridian through the point. A certain position is given to one point in any convenient sheet, and it is termed the initial point. Hensbarrow, for instance, is the initial point of the county of Cornwall, each county having an initial point from which the several stations are fixed.

The determination of a point by measurements on and perpendicular to the meridian passing through the initial point is termed obtaining the "meridianal position" with reference to the initial point.

The following is the method of computing the "meridianal position" of a point.

Example (Fig. 1): Required the meridianal position of High Wilhays with reference to Hensbarrow, the initial point.

FIG. 1.



x and y are the co-ordinates of High Wilhays with reference to Hensbarrow as their origin. x is measured on the meridian, y at right angles to it.

By the table of log. distances l is given, and from the table of bearings High Wilhays bears 239° 19′ 54·00″, at Hensbarrow log l = 5·3380765

$$\theta = 239^\circ\ 19'\ 54''\cdot 00 - 180^\circ = 59^\circ\ 19'\ 54''$$

By trigonometry from Fig. 1

$$x = l \cos \theta$$
$$y = l \sin \theta$$

$$\therefore \text{ Log } x = \log l + \text{L} \cos \theta - 10 \quad \left.\begin{array}{l} \text{Log } l \quad = 5\cdot 3380765 \\ \text{L} \cos \theta = 9\cdot 7076277 \end{array}\right.$$
$$= 5\cdot 0457042 \text{ N} \quad . \quad . \qquad \underline{5\cdot 0457042}$$

$$\text{And log } y = \log l + \text{L} \sin \theta - 10 \quad \left.\begin{array}{l} \text{Log } l \quad = 5\cdot 3380765 \\ \text{L} \sin \theta = 9\cdot 9345663 \end{array}\right.$$
$$= 5\cdot 2726428 \text{ E} \quad . \quad . \qquad \underline{5\cdot 2726428}$$

Now if x' and y' represent the natural numbers corresponding to log x and log y respectively,

$$x' = 111{,}097\cdot 5 \text{ N}, \ y' = 187{,}345\cdot 3 \text{ E}.$$

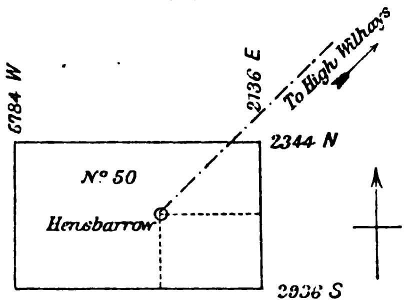
In Fig. 1 the position of the north point is shown, and from it a distance is obtained for x' measured N on the meridian, and for y' E perpendicular to the meridian.

In like manner the position of other points may be determined from stations already fixed, it being advisable to determine the mean position of a point from stations round the point whose positions have been finally determined.

As previously stated the initial point is placed anywhere in a convenient sheet. Let it be assumed that the triangulation under consideration is to be plotted to the $\frac{1}{2500}$ scale (25·344 inches to a mile) and that each of the sheets is to measure by scale $1\frac{1}{2}$ mile by 1 mile. Let Hensbarrow be situated in sheet No. 50 and its position determined by the measurements 2,936 N and 2,136 E (Fig. 2).

It may be noted that the position of a point with reference

FIG. 2.



to the sheet lines is described on the Ordnance Survey by measuring from the south towards the north, and from the east towards the west boundaries of the sheet. Hensbarrow being the initial point its value is 00.

The values of the sheet lines are assumed as in Fig. 2. To determine other sheet-line values add 5,280 feet and 7,920 feet respectively to the sheet lines, as above. Hensbarrow being the initial point all sheet lines to the right and left of it are respectively figured E and W, and those above and below N and S. In plotting the position of a point the values of the sheet lines and the meridianal position of the point must be given.

Suppose, for example, it is required to plot the position of High Wilhays.

The meridianal position of High Wilhays is

111,097·5 N, 187,345·3 E.

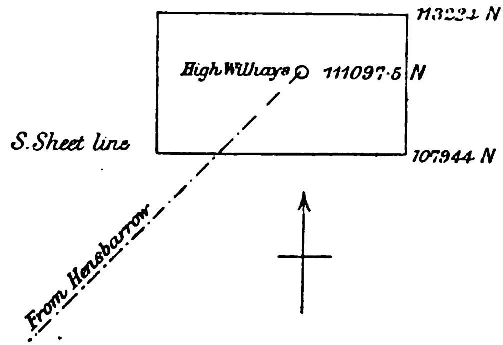
As remarked previously the sheet-line measurements are towards the N and W from the S and E sheet-lines. Therefore the S sheet-line value of the sheet in which High Wilhays is situated must be less than the distance 111,097·5 feet on the meridian.

Now the distance of Hensbarrow from the northern sheet line of sheet No. 50 is 2,344 feet, and if this quantity be taken from 111,097·5 feet and the difference divided by 5,280 (the length of each sheet on the meridian) the quotient 20 represents the number of sheet lines above 2,344, the 20th one being the southern boundary of the sheet in which the point lies.

Hence the value of the sheet line next below 111,097·5 N will be $5{,}280 \times 20 + 2{,}344 = 107{,}944$.

Now referring to the Fig. 3, the position of High Wilhays measured on the meridian will be as below:—

FIG. 3.



High Wilhays on meridian	= 111,097·5 N.
S. sheet line	= 107,944·0 N.
Difference	= 3,153·5 N.

This quantity gives the distance in feet required.

In order to obtain the position of High Wilhays in this sheet perpendicular to the meridian through Hensbarrow, proceed thus:—

High Wilhays perpendicular to meridian	= 187,345·3 E.
E. Sheet line, Sheet No. 50	= 2,136·0
Difference	= 185,209·3

Length of each sheet measured perpendicular to the meridian $= 1\frac{1}{2}$ mile $= 7{,}920$ feet.

$$\therefore \frac{185{,}209 \cdot 3}{7{,}920} = 23 \text{ sheets.}$$

But the value of the sheet line must be greater than 187,345·3, therefore there must be twenty-four sheets,

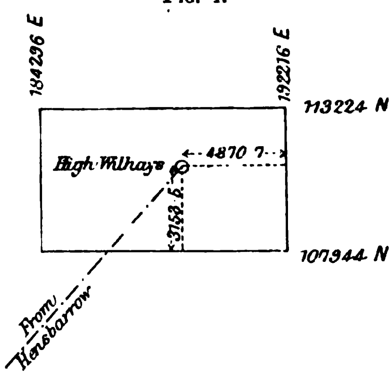
$\therefore$ 24 × 7,920 + 2,136 = 192,216 the value of the E sheet line

$\therefore$ E Sheet line	=	192,216·0 E
High Wilhays perpendicular to the meridian	=	187,345·3 E
Difference	=	4,870·7

This quantity gives the distance in feet required, and must be measured from the eastern boundary of the sheet towards the west. The point as plotted in the sheet will then appear as in Fig. 4.

This example will serve to explain the method of plotting the several points on the survey, and to these the detail work is ordinarily connected.

FIG. 4.



It is often useful to determine the distance between two stations when their meridianal positions are given. The following example shows how this may be done; the example is the converse of the one above, in which it was shown how to determine the meridianal position of a station with reference to another, when the bearing of one from the other is known and the distance between the stations.

Having given the meridianal position of High Wilhays with reference to Hensbarrow, whose position is 00, then for the meridianal position of High Wilhays:—

x = 111097·5 N. y = 187345·3 E.

Log 111097·5 = 5·0457042

Log 187345·3 = 5·2726428

9·7730614 = difference between greatest and least logs, the index of the least log being increased by 10.

Put L tan θ = 9·7730614
then θ = 30° 40′ 5·98″
and ∴ L cos θ = 9·9345663

The greatest log above	= 5·2726428
L cos θ	= 9·9345663
Difference between the greatest log whose index is increased by 10 and L cos θ	= 5·3380765

This is the log of the required distance, the natural number corresponding to which is 217,809·3 feet. If the distances between any other points are required for values of x and y, take the difference between the meridianal positions of each referred to the initial point, and proceed as above.

In conclusion, a practical example of obtaining the latitude and longitude of a station will be given in detail, as it is often useful, especially on small-scale maps, to show the latitude and longitude of stations. Required the latitude and longitude of Trevose Head. Given the latitude and longitude of Hensbarrow, and the meridianal position of Trevose Head, with reference to Hensbarrow.

Lat. Hensbarrow . . = 50° 23′ 0·73″ N.
Long. „ . . = 4° 49′ 3·23″ W.
Meridianal position of Trevose Head x = 60256·7 N y = 49705·9 W.

The first step is to compute the mid-latitude of the two stations.

Log of arc in feet = log x	= 4·7800053
Arithmetical complement of the logarithm of the number of feet in 1″ for latitude 50° 23′ 0·73″ (on meridian)	= 7·9941093 (Table V.)
Arithmetical complement of log 2 .	= 9·6989700
Sum = log of arc in seconds . .	= 2·4730846
∴ Arc in seconds. . . . . = 297·22″	= 0° 4′ 57·22″ N.
Latitude of Hensbarrow	= 50° 23′ 0·73″ N.
Mid-latitude	= 50° 27′ 57·95″ N.

The next process is to find the arithmetical complement of the log, of the number of feet in a second of arc on the meridian at the mid-latitude.

By Table V 50° 20′	= 7·99411306
By proportion, value for 7′ 57·95″	= 992
∴ 50° 27′ 57·95″ = log $\frac{1}{\mu}$	= 7·99410314

which quantity represents the arithmetical complement of the log of the number of feet in a second of arc for latitude 50° 27′ 57·95″ on the meridian of Hensbarrow.

$$\begin{array}{ll} \text{Now log } x \ \ldots\ldots & = 4\cdot7800053 \\ \text{Log } \frac{1}{\mu} \ \ldots\ldots & = 7\cdot9941031 \\ \hline \text{Sum} \ \ldots\ldots & = 2\cdot7741084 = \text{log of arc in seconds} \end{array}$$

$$\therefore \text{ Arc in seconds} = 594\cdot44'' = 0^\circ\ 9'\ 54\cdot44'',$$

which is an approximate difference of latitude between the stations, requiring for true latitude a correction for spherical excess.

$$\begin{array}{ll} & \ \ {}^\circ\ \ \ \ {}'\ \ \ \ {}'' \\ \text{Now latitude of Hensbarrow} \ \ldots & = 50\ 23\ \ 0\cdot73 \text{ N.} \\ \text{Approximate difference of latitude} \ . & = \ 0\ \ 9\ 54\cdot44 \\ \hline \text{Approximate latitude of Trevose Head} & = 50\ 32\ 55\cdot17 = \phi. \end{array}$$

To obtain the true latitude of Trevose Head, the spherical excess must be deducted from the value ϕ.

Calculation for spherical excess:

$$\begin{array}{llll} \text{Arithmetical complement of log } 2\nu^2 \sin 1'' \text{ for given latitude} & & & = 0\cdot37158 \\ \quad ,, \quad\quad ,, & 2 \log y & ,, & = 9\cdot39282 \\ \quad ,, \quad\quad ,, & \text{L} \tan \phi & ,, & = 0\cdot08465 \\ \hline & \text{Sum} = \text{log of number of seconds} & & = \bar{1}\cdot84905 \end{array}$$

$$\therefore \text{ seconds} = \text{S. E.} = 0\cdot71''.$$

$$\begin{array}{ll} & \ \ {}^\circ\ \ \ \ {}'\ \ \ \ {}'' \\ \text{Now the approximate latitude of Trevose Head} & = 50\ 32\ 55\cdot17 \text{ N.} \\ -\text{ S. E.} & = \quad\quad\ -0\cdot71 \\ \hline \therefore \text{ True latitude of Trevose Head} & = 50\ 32\ 54\cdot46 \text{ N.} \end{array}$$

To determine the longitude of Trevose Head—

$$\begin{array}{ll} & \ \ {}^\circ\ \ \ \ {}'\ \ \ \ {}'' \\ \text{Latitude Trevose Head} & = 50\ 32\ 54\cdot46 \\ +\tfrac{1}{3}\text{ S. E.} & = \quad\quad\ \ 0\cdot24 \\ \hline & \ \ 50\ 32\ 54\cdot70 = \theta. \end{array}$$

$$\begin{array}{ll} \text{Now L sec } \theta & = 0\cdot1969361 \\ \text{Log } y & = 4\cdot6964079 \\ \text{Log } \frac{1}{\varpi} \text{ Table V} & = 7\cdot9929210 = \left\{ \begin{array}{l} \text{Arithmetical complement of the log of} \\ \text{the number of feet in a second of arc} \\ \text{perpendicular to the meridian for} \\ 50^\circ\ 32'\ 54\cdot70''. \end{array} \right. \\ \hline \left.\begin{array}{l}\text{Sum} = \text{log of arc} \\ \text{in seconds.}\end{array}\right\} & 2\cdot8862650 \end{array}$$

$\therefore$ Arc in seconds = 769·60″	=	0° 12′ 49″·60 W.
= Difference of longitude between the stations—		
Longitude of Hensbarrow	=	4 49 3·23 W.
$\therefore$ Longitude of Trevose Head	=	5 1 52·83 W.

The foregoing examples should serve to explain the various methods of computation which constitute the principal duties of the computing branch of a trigonometrical survey.

It would require an intimate knowledge of several of the higher branches of mathematics to thoroughly understand the principles on which the various formulas are based. The object of this Paper has been to explain, by practical examples, the principal calculations that occur in the conduct of a trigonometrical survey, and not of discussing the formulas on which they are based, as what is required by the civil engineer and surveyor is the "rule of thumb" methods of working them.

In the early part of 1884 the Author attended some lectures on trigonometrical surveying, and, desirous of fortifying his memory, compiled his notes in the form of a Paper. The several bearings, &c., have been obtained from the Ordnance Survey Office, Southampton.

This communication is accompanied by a map and several diagrams, from which Plate 5 and the Figs. in the text have been prepared.

[APPENDIX.

APPENDIX.

Table I.—Observations made with a 12-inch Theodolite at Docking Church Tower.

No. of Arc.	Objects.	Vernier Readings.					Mean of Seconds.	Reading in Abstract.		
		°	'	A"	B"	C"		°	'	"
	Constant	+9	41	..	..	..	+0·8 m(39·2)			
	T. P. Brancaster Farm R. O.	173	53	30	39	39	36·0	183	34	40·0
	„ Brancaster Field House . . .	195	5	0	10	14	8·0	204	46	8·8
	„ Manor Farm .	76	6	36	49	60	48·3	85	47	49·1
	Vane Great Bircham Church Tower.	345	34	50	64	69	61·0	355	15	61·8
	„ Sandringham Waterworks Tr.	25	34	29	37	46	37·3	35	15	38·1
1	T. P. Waters Farm .	58	15	18	34	41	31·0	67	56	31·8
	„ Pettymy Farm .	53	40	24	36	47	35·7	63	21	36·5
	Vane Snethsham Ch. Spire . .	62	30	34	43	57	44·7	72	11	45·5
	T. P. West Hall . .	65	42	15	24	40	26·3	75	23	27·1
	„ Antheny's Farm	81	36	37	41	55	44·3	91	17	45·1
	Vane Heacham Ch. Tower . . .	89	9	41	51	64	52·0	98	50	52·8
	T. P. Summerfield .	106	12	53	63	75	63·7	115	53	64·5
	R. O.	173	53	32	45	50	42·3	..	..	..
	Constant	−27	0	..	..	..	−13·5 m(53·5)			
	R. O.	210	34	36	54	61	50·3	183	34	40·0
	T. P. Brancaster Field House . . .	231	46	2	16	24	14·0	204	46	0·5
	Vane Great Bircham Church Tower.	22	16	5	11	17	11·0	365	15	57·5
	„ Sandringham Waterworks Tr.	62	15	34	43	47	41·3	35	15	27·8
2	T. P. Pettymy Farm .	90	21	41	44	54	46·3	63	21	32·8
	„ Waters Farm .	94	56	37	40	53	43·3	67	56	29·8
	Vane Snethsham Ch. Spire . . .	49	11	43	52	68	54·3	72	11	40·8
	T. P. West Hall . .	102	23	30	36	54	40·0	75	23	26·5
	„ Antheny's Farm	118	17	46	56	72	58·0	91	17	44·5
	„ Manor Farm .	112	47	48	57	73	59·3	85	47	45·8
	Vane Heacham Ch. Tower . . .	125	50	53	65	80	66·0	98	50	52·5
	T. P. Summerfield .	142	54	1	13	26	13·3	115	53	59·8
	R. O.	210	34	43	60	67	56·7	..	..	..

TABLE I.—*continued.*

No. of Arc.	Objects.	Vernier Readings.					Mean of Seconds.	Reading in Abstract.		
		°	′	A″	B″	C″		°	′	″
3	Constant	−61	52	..	..	..	−39·8 m(19·8)			
	R. O.	245	27	9	24	28	20·3	183	34	40·0
	T. P. Field House .	258	30	41	56	60	52·3	196	38	12·5
	" Brancaster Field House . . .	266	38	36	50	56	47·3	204	46	7·5
	Vane Great Bircham Ch. Tower . .	57	8	27	37	45	36·3	355	15	56·5
	" Sandringham Waterworks Tr.	97	8	5	12	24	13·7	35	15	33·9
	T. P. Pettymy Farm .	125	14	1	11	20	10·7	63	21	30·9
	" Waters Farm .	129	49	9	18	25	17·3	67	56	37·5
	Vane Snethsham Ch. Spire . . .	134	4	11	23	30	21·3	72	11	41·5
	T. P. Manor Farm .	147	40	13	23	30	22·0	85	47	42·2
	Vane Heacham Ch. Tower . . .	160	43	20	28	38	28·7	98	50	48·9
	T. P. Summerfield .	177	46	32	38	49	39·7	115	53	59·9
	R. O.	245	27	11	20	27	19·3	..	..	..
4	Constant	−96	44	..	..	..	−43·5 m(23·5)			
	R. O.	280	19	20	28	36	28·0	183	34	40·0
	T. P. Field House .	293	22	52	60	68	60·0	196	38	16·5
	" Barrow Common	299	8	4	12	20	12·0	202	23	28·5
	" Brancaster Field House . . .	301	30	49	56	64	56·3	204	46	12·8
	R. O.	280	19	10	22	25	19·0	..	..	..
5	Constant	−96	44	..	..	..	−43·0 m(23·0)			
	R. O.	280	19	16	25	28	23·0	183	34	40·0
	T. P. Field House .	293	22	51	60	66	59·0	196	38	16·0
	" Barrow Common	299	7	59	69	72	66·7	202	23	23·7
	" Brancaster Field House . . .	301	30	49	55	60	54·7	204	46	11·7
	" Sussex Farm .	308	42	18	25	29	24·0	211	57	41·0
	R. O.	280	19	13	24	32	23·0	..	..	..
6	Constant	+123	28	..	..	..	+20·0 m(20·0)			
	R. O.	60	6	10	23	29	20·7	183	34	40·0
	Top Holkham Monument	119	37	22	34	44	33·3	243	5	53·3
	Cocksford Wood . .	191	22	40	52	58	50·0	314	51	10·0
	Vane Snethsham Ch. Spire	308	43	15	24	28	22·3	72	11	42·3
	R. O.	60	6	15	20	23	19·3	..	..	..

TABLE I.—*continued.*

No. of Arc.	Objects.	Vernier Readings.					Mean of Seconds.	Reading in Abstract.		
		°	′	A″	B″	C″		°	′	″
7	Constant	+157	44	..	..	..	+26·5 m(13·5)			
	R. O.	25	50	5	14	26	15·0	183	34	40·0
	T. P. Field House .	38	53	35	46	55	45·3	196	38	11·8
	„ Barrow Common	44	38	41	53	64	52·7	202	23	19·2
	„ Brancaster Field House . . .	47	1	30	40	51	40·3	204	46	6·8
	„ Sussex Farm .	54	12	58	68	79	68·3	211	57	34·8
	Top Holkam Monument	85	21	21	29	38	29·3	243	5	55·8
	T. P. Cocksford Wood	157	6	30	37	48	38·3	314	51	4·8
	Vane Snethsham Ch. Spire	274	26	58	68	79	68·3	72	11	34·8
	R. O.	25	50	1	12	23	12·0	..	..	..
8	Constant	+123	28	..	..	..	+20·0 m(20·0)			
	R. O.	60	6	14	20	28	20·7	183	34	40·0
	T. P. Elgar's Wood .	206	11	4	11	28	14·3	329	39	34·3
	Vane Great Bircham Ch. Tower . .	231	47	26	34	46	35·3	355	15	55·3
	„ Sandringham Waterworks Tr.	271	47	5	12	22	13·0	35	15	33·0
	R. O.	60	6	10	22	26	19·3	..	..	..
9	Constant	+88	16	..	..	..	+42·0 m(58·0)			
	R. O.	95	17	48	60	70	59·3	183	34	40·0
	T. P. Fakenham Ch. Tower	209	6	10	25	29	21·3	297	22	63·3
	Vane Syderstone Ch. Tower	216	13	39	54	55	49·3	304	30	31·3
	T. P. Cocksford Wood	226	34	18	28	32	26·0	314	51	8·0
	„ Elgar's Wood .	241	22	42	54	54	50·0	329	39	32·3
	Vane Sandringham Waterworks Tower .	306	58	43	49	56	49·3	35	15	31·3
	T. P. Sandringham Heath	318	19	8	15	20	14·3	46	35	56·3
	R. O.	95	17	48	55	67	56·7	..	..	..
10	Constant	+18	14	..	..	..	+13·3 m(26·7)			
	R. O.	165	20	18	24	33	25·0	183	34	40·0
	T. P. Fakenham Ch. Tower . . .	279	8	38	48	58	48·0	297	22	61·3
	„ Elgar's Wood .	311	25	11	22	32	21·7	329	39	35·0
	Vane Sandringham Waterworks Tower .	17	1	12	20	33	21·7	35	15	35·0
	R. O.	165	20	19	31	35	28·3	..	..	..

TABLE I.—*continued.*

No. of Arc.	Objects.	Vernier Readings. °	′	A″	B″	C″	Mean of Seconds.	Reading in Abstract. °	′	″
11	Constant	−16	32	..	..	..	−40·3 m(20·3)			
	R. O.	200	7	12	23	31	22·0	183	34	40·0
	T. P. Fakenham Ch. Tower	313	55	31	38	44	37·7	297	22	57·4
	Vane Syderstone Ch. Tower	321	3	4	13	16	11·0	304	30	30·7
	T. P. Cockseford Wood .	331	23	45	50	55	50·0	314	51	9·7
	„ Elgar's Wood .	346	12	9	12	20	13·7	329	39	33·4
	Vane Sandringham Waterworks Tower .	51	48	5	8	21	11·3	35	15	31·0
	T. P. Sandringham Heath	63	8	30	34	46	36·7	46	35	56·4
	R. O.	200	7	8	16	32	18·7	..	..	..
12	Constant	+108	17	..	..	..	+52·0 m(48·0)			
	R. O.	75	16	39	49	50	46·0	183	34	40·0
	T. P. Elgar's Wood .	221	21	36	42	52	43·3	329	39	35·3
	„ Sandringham Heath . . .	298	18	0	4	19	7·7	46	35	59·7
	Vane Heacham Church Tower . . „ .	350	32	55	60	71	62·0	98	50	54·0
	R. O.	75	16	38	51	61	50·0	..	..	..

TABLE II.—ABSTRACT of OBSERVATIONS TAKEN with a 12-inch THEODOLITE at DOCKING CHURCH TOWER.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
No. of Arc.	T. P. Brancaster Farm (R. O.).	T. P. Brancaster Field House.	T. P. Manor Farm.	Vane Great Bircham Church Tower.	Vane Sandringham Water Works Tower.	T. P. Waters Farm.	T. P. Pettymy Farm.	Vane Snetsham Church Spire.	T. P. West Hall.	T. P. Anthony's Farm.	Vane Heacham Church Tower.	T. P. Summerfield.	T. P. Field House.	T. P. Barrow Common.	T. P. Sussex Farm.	Top of Holkham Monument.	T. P. Cocksford Wood.	T. P. Sandringham Heath.	T. P. Fakenham Church Tower.	T. P. Elgar's Wood.	Vane Syderstone Church Tower.	No. of Arc.
	° 183 ′ 34	° 204 ′ 46	° 85 ′ 47	° 355 ′ 15	° 35 ′ 15	° 67 ′ 56	° 63 ′ 21	° 72 ′ 11	° 75 ′ 23	° 91 ′ 17	° 98 ′ 50	° 115 ′ 53	° 196 ′ 38	° 202 ′ 23	° 211 ′ 57	° 243 ′ 5	° 314 ′ 51	° 46 ′ 35	° 297 ′ 22	° 329 ′ 39	° 304 ′ 30	
	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	
1	40·0	8·8	49·1	61·8	38·1	31·8	36·5	45·5	27·1	45·1	52·8	64·5	..	..	..	..	..	..	..	..	..	1
2	,,	0·5	45·8	57·5	27·8	29·8	32·8	40·8	26·5	44·5	52·5	59·8	..	..	..	..	..	..	..	..	..	2
3	,,	7·5	42·2	56·5	33·9	37·5	30·9	41·5	..	..	48·9	59·9	12·5	..	..	..	..	..	..	..	..	3
4	,,	12·8	..	..	..	..	..	..	..	..	..	..	16·5	28·5	..	..	..	..	..	..	..	4
5	,,	11·7	..	..	..	..	..	..	..	..	..	..	16·0	23·7	41·0	..	..	..	..	..	..	5
6	,,	..	..	..	..	..	..	42·3	..	..	..	..	..	..	..	53·3	10·0	..	..	..	..	6
7	,,	6·8	..	..	..	..	..	34·8	..	..	..	..	11·8	19·2	34·8	55·8	4·8	..	..	..	..	7
8	,,	..	..	55·3	33·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	34·3	..	8
9	,,	..	..	..	31·3	..	..	..	..	..	..	..	..	..	..	..	8·0	56·3	63·3	32·3	31·3	9
10	,,	..	..	..	35·0	..	..	..	..	..	..	..	..	..	..	..	..	..	61·3	35·0	..	10
11	,,	..	..	..	31·0	..	..	..	..	..	..	..	..	..	..	..	9·7	56·4	57·4	33·4	30·7	11
12	,,	..	..	..	..	..	..	..	..	..	54·0	..	..	..	..	..	..	59·7	..	35·3	..	12
	40·0	8·0	45·7	57·8	32·9	33·0	33·4	41·0	26·8	44·8	52·1	61·4	14·2	23·8	37·9	54·6	8·1	57·5	60·7	31·1	31·0	Final means of seconds.
	..	5·30	5·29	3·00	2·64	7·09	3·60	4·85	0·09	0·09	1·81	3·20	2·15	9·61	9·61	1·57	2·13	1·66	4·00	0·48	0·09	Reciprocal of weights.

To calculate the Reciprocal of the Weight of an Observation.

Example.—Column 2. T. P. Brancaster Field House.

Final mean of seconds = 8·0″.

		Mean.	Error.	Square of Error.
Arc 1	8·8	8·0	+0·8	0·64
,, 2	0·5	,,	−7·5	56·25
,, 3	7·5	,,	−0·5	0·25
,, 4	12·8	,,	+4·8	23·04
,, 5	11·7	,,	+3·7	13·69
,, 6	6·8	,,	−1·2	1·44
				95·31
				2

Twice sum of squares of errors . . = } 190·62

And square of number of observations = $6^2 = 36$

∴ by rule we have $\frac{190\cdot62}{36} = 5\cdot30$

= reciprocal of weight

TABLE III of SPHERICAL BEARINGS.—PRIMARY TRIANGULATION.

At Precelly (3 feet).

	°	′	″	Reciprocal of weights.
Cradle	268	59	42·98	0·25
Dunkerry	316	7	6·48	0·30
Paracombe	323	8	49·46	0·24
High Wilhays	338	53	39·85	0·41
Lundy Island	355	16	17·92	1·05

At Cradle (3 feet).

	°	′	″	Reciprocal of weights.
Dunkerry	18	59	23·79	0·12
Paracombe	29	37	33·18	0·31
Precelly	89	0	0·29	0·21
Mendip	332	18	18·99	0·22

At Paracombe (3 feet).

	°	′	″	Reciprocal of weights.
High Wilhays	10	15	31·63	0·79
Brown Willy	38	16	11·46	1·76
Lundy Island	88	37	14·56	2·37
Precelly	143	8	49·95	0·68
Cradle	209	37	38·81	0·30
Dunkerry	273	25	47·98	0·91

At Dunkerry (3 feet).

	°	′	″	Reciprocal of weights.
High Wilhays	28	31	35·31	0·76
Paracombe	93	25	47·44	0·77
Precelly	136	7	10·17	0·50
Cradle	198	59	35·45	0·72
Mendip	263	46	0·59	0·29
Pillesden	305	34	12·27	0·47

At Pillesden (3 feet).

	°	′	″	Reciprocal of weights.
High Wilhays	79	58	51·55	0·61
Dunkerry	125	53	13·87	0·39
Mendip	202	32	12·28	0·65

At Mendip (3 feet).

	°	′	″	Reciprocal of weights.
Pillesden	22	32	15·88	5·74
High Wilhays	59	11	11·60	1·50
Dunkerry	84	5	13·69	0·24
Cradle	152	37	59·53	0·66

At Lundy Island (3 feet).

	°	′	″	Reciprocal of weights.
Hensbarrow	6	41	58·41	0·05
Trevose Head	20	15	11·49	0·52
Precelly	175	16	8·04	0·17
Paracombe	268	37	18·46	0·36
High Wilhays	318	41	20·98	0·22
Brown Willy	355	28	1·83	0·20

TABLE III.—*continued.*

At High Wilhays (3 feet).

	°	′	″	Reciprocal of weights.
Deadman	47	6	14·07	0·30
Hensbarrow	59	19	47·54	0·97
Brown Willy	75	29	17·04	0·65
Lundy Island	138	41	27·09	0·13
Precelly	158	53	45·55	0·32
Paracombe	190	15	46·56	0·61
Dunkerry	208	31	54·04	0·64
Mendip	238	52	28·42	0·39
Pillesden	259	40	19·36	0·15
Ryder's Hill	336	17	1·45	0·39

At Brown Willy (18 inches).

Hensbarrow	33	37	9·41	1·43
Trevose Head	81	15	42·76	0·28
Lundy Island	175	28	7·99	1·11
Paracombe	218	16	29·15	1·25
High Wilhays	255	29	18·79	1·51
Ryder's Hill	280	8	7·63	4·21

At Barrow Hill (3 feet).

Hensbarrow	101	45	47·21	1·07
Ryder's Hill	154	52	48·66	0·16
Pillesden	222	17	24·45	0·33
Maker Church Tower	110	6	43·32	1·48

At Ryder's Hill (3 feet).

Deadman	63	35	52·05	0·14
Hensbarrow	77	58	15·43	0·44
Brown Willy	100	8	6·04	0·57
High Wilhays	156	17	7·65	0·49
Pillesden	244	46	3·87	0·83

At Hensbarrow (3 feet).

Trevose Head	140	28	49·72	1·02
Lundy Island	186	41	58·46	9·27
Brown Willy	213	37	11·71	2·29
High Wilhays	239	19	54·00	0·18
Maker Church Tower	274	52	40·46	2·00
Deadman	356	2	10·06	0·18

At Maker Church Tower (8 feet).

Deadman	72	5	17·58	0·52
Hensbarrow	94	52	37·55	0·16
High Wilhays	197	37	41·41	0·22

TABLE III.—*continued.*

At Deadman (3 feet).

	°	′	″	Reciprocal of weights.
Hensbarrow	176	2	11·48	0·62
Brown Willy	198	54	53·10	0·31
High Wilhays	227	6	20·07	0·39
Ryder's Hill	243	35	56·89	0·17

At Trevose Head (3 feet).

	°	′	″	Reciprocal of weights.
Lundy Island	200	15	1·87	0·18
Brown Willy	261	15	39·72	0·44
Hensbarrow	320	28	48·74	0·83

TABLE IV.—SOLUTION of PRIMARY TRIANGULATION.

Calculation for Spherical Excess.	Names of Stations.	Angles Observed.	Weights.	Apportionment of Error.	One-third Sph. Excess.	Angles for Computation.	Calculation.	Remarks.
	1		Base. Precelly to Cradle =				5·5712951	
		° ′ ″		+	−	° ′ ″		
5·57129	Precelly . .	54 9 6·48	0·49	0·59	8·28	54 8 58·79	9·9087796	
9·93476	Cradle . .	59 22 27·11	0·52	0·63	8·28	59 22 19·46	9·9347478	
5·51775	Paracombe .	66 28 48·86	0·98	1·18	8·29	66 28 41·75	0·0376740	
0·37158								
1·39538	Sum . =	180 0 22·45	1·99	Cradle to Paracombe =			5·5177487	
″	180°+ E. =	180 0 24·85		Precelly to ,, =			5·5437169	Used 5.
=24·85	Error . =	−2·40						
	2		Base. Precelly to Cradle =				5·5712951	
		° ′ ″				° ″ ″		
5·57129	Precelly . .	47 7 23·50	0·55	Nil	8·42	47 7 15·08	9·8649800	
9·97303	Cradle . .	70 0 36·50	0·33	,,	8·43	70 0 28·07	9·9730073	
5·48688	Dunkerry .	62 52 25·28	1·22	,,	8·43	62 52 16·85	0·0506174	
0·37158								
1·40278	Sum . =	180 0 25·28	2·10	Cradle to Dunkerry =			5·4868925	Used.
″	180°+ E. =	180 0 25·28		Precelly to ,, =			5·5949198	Used 7.
=25·28	Error . =	Nil						
	3		Base. Cradle to Dunkerry =				5·4868925	
		° ′ ″				° ′ ″		
5·48688	Cradle . .	46 41 4·80	0·34	0·01	5·22	46 40 59·57	9·8618759	
9·95644	Dunkerry .	64 46 25·14	1·01	0·06	5·22	64 46 19·86	9·9564663	
5·37993	Mendip . .	68 32 45·84	0·90	0·05	5·22	68·32 40·57	0·0311890	
0·37158								
1·19483	Sum . =	180 0 15·78	2·25	Dunkerry to Mendip =			5·3799574	Used.
″	180°+ E. =	180 0 15·66		Cradle to ,, =			5·4745478	
=15·66	Error . =	+0·12						
	4		Base. Precelly to Paracombe =				5·5437169	
		° ′ ″				° ′ ″		
5·54372	Precelly . .	32 7 28·46	1·29	0·48	4·16	32 7 23·82	9·7257016	
9·91083	Paracombe .	54 31 35·39	3·05	1·12	4·16	54 31 30·11	9·9108213	
5·27019	Lundy Island	93 21 10·42	0·53	0·19	4·16	93 21 6·07	0·0007435	
0·37158								
1·09632	Sum . =	180 0 14·27	4·87	Paracombe to Lundy =			5·2701620	Used.
″	180°+ E. =	180 0 12·48		Precelly to ,, =			5·4552817	8
=12·48	Error . =	+1·79						

TABLE IV.—*continued.*

Calculation for Spherical Excess.	Names of Stations.	Angles Observed.	Weights.	Apportionment of Error.	One-third Sph. Excess.	Angles for Computation.	Calculation.	Remarks.
	5		Base.	Precelly to Dunkerry =			5·5949198	
		° ′ ″		+	−	° ′ ″		
5·59492	Precelly . .	7 1 42·98	0·54	0·04	1·32	7 1 41·70	9·0876349	
9·83119	Dunkerry .	42 41 22·73	1·27	0·08	1·32	42 41 21·49	9·8312441	
4·80042	Paracombe .	130 16 58·03	1·59	0·10	1·32	130 16 56·80	0·1175514	
0·37158								
0 59811	Sum . =	180 0 3·74	3·40	Dunkerry to Paracombe =			4·8001061	10.
″	180°+ E. =	180 0 3·96		Precelly to ″ =			5·5437153	Used 1.
=3·96	Error . =	−0·22						
	6		Base.	Precelly to Paracombe =			5·5437153	
		° ′ ″		+	−	° ′ ″		
5·54371	Precelly . .	15 44 50·39	0·65	0·27	3·66	15 44 47·00	9·4335775	
9·86491	Paracombe .	132 53 18·32	1·47	0·62	3·66	132 53 15·28	9·8649205	
5·26095	High Wilhays	31 22 1·01	0·93	0·38	3·67	31 21 57·72	0·2835763	
0·37158								
1·04115	Sum . =	180 0 9·72	3·05	Paracombe to H. Wilh's =			5·2608691	9, 10, 13.
″	180°+ E. =	180 0 10·99		Precelly to ″ =			5·6922121	Used.
=10·99	Error . =	−1·27						
	7	Base.		Precelly to High Wilhays =			5·6922121	
		° ′ ″		+	−	° ′ ″		
5·69221	Precelly . .	22 46 33·37	0·71	0·22	5·87	22 46 27·72	9·5878267	
9·88190	High Wilhays	49 38 8·49	0·96	0·29	5·88	49 38 2·90	9·8819118	
5·30068	Dunkerry .	107 35 34·86	1·26	0·40	5·88	107 35 29·38	0·0207998	
0·37158								
1·24637	Sum . =	180 0 16·72	2·93	H. Wilhays to Dunkerry =			5·3008386	Used 15.
″	180°+ E. =	180 0 17·63		Precelly to ″ =			5·5949237	2.
=17·63	Error . =	−0·91						
	8	Base.		Precelly to High Wilhays =			5·6922121	
		° ′ ″		−	−	° ′ ″		
5·69221	Precelly . .	16 22 38·07	1·46	0·10	3·10	16 22 34·87	9·4501652	
9·53819	High Wilhays	20 12 18·46	0·45	0·03	3·11	20 12 15·32	9·5382819	
5·36731	Lundy Island	143 25 12·94	0·39	0·02	3·11	143 25 9·81	0·2247879	
0·37158								
0·96929	Sum . =	180 0 9·47	2·30	High Wilhays to Lundy =			5·3671652	Used.
″	180°+ E. =	180 0 9·32		Precelly to ″ =			5·4552819	4.
=9·32	Error . =	+0·15						
	9	Base.		Lundy Island to High Wilhays =			5·3671652	
		° ′ ″		+	−	° ′ ″		
5·36716	Lundy Island	50 4 2·52	0·58	0·37	2·61	50 4 0·28	9·8846780	
9·89394	High Wilhays	51 34 19·47	0·74	0·48	2·61	51 34 17·34	9·8939748	
5·26085	Paracombe .	78 21 42·93	3·16	2·06	2·61	78 21 42·38	0·0090218	
0·37158								
0·89353	Sum . =	180 0 4·92	4·48	H. Whays to Paracombe =			5·2608650	6, 10, 13.
″	180°+ E. =	180 0 7·83		Lundy to ″ =			5·2701618	4.
=7·83	Error . =	−2·91						

TABLE IV.—*continued.*

Calculation for Spherical Excess.	Names of Stations.	Angles Observed.	Weights.	Apportionment of Error.	One-third Sph. Excess.	Angles for Computation.	Calculation.	Remarks.
	10	Base.	High Wilhays to Dunkerry =				5·3008386	
		° ′ ″		−	−	° ′ ″		
5·30083	High Wilhays	18 16 7·48	1·25	0·16	0·89	18 16 6·43	9·4961955	
9·95692	Dunkerry .	64 54 12·13	1·53	0·19	0·90	64 54 11·04	9·9569323	
4·80008	Paracombe .	96 49 43·65	1·70	0·22	0·90	96 49 42·53	0·0030917	
0·37158								
0·42941	Sum . =	180 0 3·26	4·48	Dunkerry to Paracombe =			4·8001258	5.
″	180°+E. =	180 0 2·69		High Wilhays to „ =			5·2608626	6, 9, 13.
=2·69	Error . =	+0·57						
	11	Base.	Lundy Island to High Wilhays =				5·3671652	
		° ′ ″		+	−	° ′ ″		
5·36716	Lundy Island	36 46 40·85	0·42	0·57	2·30	36 46 39·12	9·7772162	
9·95065	High Wilhays	63 12 10·05	0·78	1·06	2·31	63 12 8·80	9·9506593	
5·15106	Brown Willy.	80 1 10·80	2·62	3·59	2·31	80 1 12·08	0·0066218	
0·37158								
0·84045	Sum . =	180 0 1·70	3·82	H. Wilhays to B. Willy =			5·1510032	13, 21.
″	180°+ E. =	180 0 6·92		Lundy to „ =			5·3244463	12.
=6·92	Error . =	−5·22						
	12	Base.	Lundy Island to Paracombe =				5·2701620	
		° ′ ″		+	−	° ′ ″		
5·27016	Lundy Island	86 50 43·37	0·56	0·13	3·08	86 50 40·42	3·9993410	
9·88646	Paracombe .	50 21 3·10	4·13	0·94	3·08	50 21 0·96	9·8864679	
5·43735	Brown Willy.	42 48 21·16	2·36	0·54	3·08	42 48 18·62	0·1678057	
0·37158								
0·96555	Sum . =	180 0 7·63	7·05	Paracombe to B. Willy =			5·4373087	Used.
″	180°+ E. =	180 0 9·24		Lundy „ =			5·3244356	11.
=9·24	Error . =	−1·61						
	13		Base.	Paracombe to B. Willy =			5·4373087	
		° ′ ″		+	−	° ′ ″		
5·43730	Paracombe .	28 0 39·83	2·55	2·53	1·84	28 0 40·52	9·6717697	
9·78163	Brown Willy.	37 12 49·64	2·76	2·74	1·84	37 12 50·54	9·7816077	
5·15105	High Wilhays	114 46 29·52	1·26	1·26	1·84	114 46 28·94	0·0419320	
0·37158								
0·74156	Sum . =	179 59 58·99	6·57	B. Willy to H. Wilhays =			5·1510104	11, 21.
″	180°+ E. =	180 0 5·52		Paracombe to „ =			5·2608484	6, 9, 10.
=5·52	Error . =	−6·53						
	14		Base.	Dunkerry to Mendip =			5·3799578	
		° ′ ″		+	−	° ′ ″		
5·37994	Dunkerry .	41 48 11·68	0·76	0·02	2 71	41 48 8·99	9·8238425	
9·94410	Mendip . .	61 32 57·81	5·98	0·19	2·72	61 32 55·28	9·9440987	
5·21566	Pillesden .	76 38 58·41	1·04	0·04	2·72	76 38 55·73	0·0118992	
0·37158								
0·91128	Sum . =	180 0 7·90	7·78	Mendip to Pillesden =			5·2156995	
″	180°+ E. =	180 0 8·15		Dunkerry to „ =			5·3359557	Used.
=8·15	Error . =	−0·25						

TABLE IV.—*continued.*

Calculation for Spherical Excess.	Names of Stations.	Angles Observed.	Weights.	Apportionment of Error.	One-third Sph. Excess.	Angles for Computation.	Calculation.	Remarks.
	15		Base.	Dunkerry to Pillesden =			5·3359557	
5·33594		° ′ ″		–	–	° ′ ″		
9·85620	Dunkerry .	82 57 23·04	1·23	0·23	3·37	82 57 19·44	9·9967091	
5·44133	Pillesden .	45 54 22·32	1·00	0·18	3·37	45 54 18·77	9·8562391	
0·37158	High Wilhays	51 8 25·32	0·79	0·15	3·38	51 8 21·79	0·1086440	
1·00505	Sum . =	180 0 10·68	3·02	Pillesden to H. Wilhays =			5·4413088	Used.
″	180° + E. =	180 0 10·12		Dunkerry to „ =			5·3008388	7.
=10·12								
	Error . =	+0·56						
5·44129	16	Base.		High Wilhays to Pillesden =			5·4413088	
9·41015		° ′ ″			–	° ′ ″		
5·42949	High Wilhays	76 36 42·09	..	..	1·49	76 36 40·60	9·9880331	
0·37158	Pillesden .	14 54 21·69	(Supplementary)			14 54 28·68	9·4103527	
	Ryder's Hill.	88 28 56·22	..	..	1·50	88 28 54·72	0·0001525	
0·65251								
″				Pillesden to Ryder's Hill =			5·4294944	
=4·49	180° + E. =	180 0 4·49		High Wilhays to „ =			4·8518140	18, 21.
	17	Base.		Lundy Island to High Wilhays =			5·3671652	
5·36716		° ′ ″		–	–	° ′ ″		
9·99247	Lundy Island	48 0 37·43	0·27	0·02	3·91	48 0 33·50	9·8711370	
5·33811	High Wilhays	79 21 39·55	1·10	0·08	3·91	79 21 35·56	9·9924679	
0·37158	Hensbarrow .	52 37 55·54	9·45	0·69	3·91	52 37 50·94	0·0997743	
1·06932	Sum . =	180 0 12·52	10·82	H. Whys. to Hensbarrow =			5·3380765	Used.
″	180° + E. =	180 0 11·73		Lundy to „ =			5·4594074	
=11·73								
	Error . =	+0·79						
5·33807	18	Base.		High Wilhays to Hensbarrow =			5·3380765	
9·50448		° ′ ″			–	° ′ ″		
5·34396	High Wilhays	83 2 46·09	..	..	1·20	83 2 44·89	9·9967932	
0·37158	Hensbarrow .	18 38 21·69	(Supplementary)			18 38 24·10	9·5046358	
	Ryder's Hill.	78 18 52·22	..	..	1·21	78 18 51·01	0·0090963	
0·55809				Hensbarrow to Ryder's Hill =			5·3439660	
″								
=3·62	180° + E. =	180 0 3·62		High Wilhays to „ =			4·8518086	16, 21.
5·33807	19	Base.		High Wilhays to Hensbarrow =			5·3380765	
9·76448		° ′ ″			–	° ′ ″		
5·17189	High Wilhays	41 42 9·68	(Supplementary)			41 42 12·63	9·8230019	
0·37158	Hensbarrow .	35 32 46·46	...	..	1·47	35 32 44·99	9·7644406	
	Maker Ch. Tr.	102 45 3·86	..	..	1·48	102 45 2·38	0·0108441	
0·64602								
″				Hensbarrow to Maker Ch. Tr. =			5·1719225	
=4·43	180° + E. =	180 0 4·43		High Wilhays to „ =			5·1133612	

TABLE IV.—*continued.*

Calculation for Spherical Excess.	Names of Stations.	Angles Observed.	Weights.	Apportionment of Error.	One-third Sph. Excess.	Angles for Computation.	Calculation.	Remarks.
5·34396	20	Base.	Hensbarrow to Ryder's Hill =				5·3439660	
9·57668		° ′ ″			–	° ′ ″		
5·22601	Hensbarrow .	44 21 7·61	(Supplementary)			44 21 9·81	9·8445229	
0·37158	Ryder's Hill.	22 9 50·61	..	..	1·10	22 9 49·51	9·5766350	
	Brown Willy.	113 29 1·78	..	..	1·10	113 29 0·68	0·0375479	
0·51823								
″			Ryder's Hill to Brown Willy =				5·2260368	Used
=3·30	180°+ E. =	180 0 3·30	Hensbarrow to „ =				4·9581489	
	21	Base.	Brown Willy to Ryder's Hill =				5·2260368	
5·22603		° ′ ″		–	–	° ′ ″		
9·91934	Brown Willy.	24 38 48·84	5·72	2·71	0·78	24 38 45·35	9·6201460	
4·85182	Ryder's Hill.	56 9 1·61	1·06	0·50	0·78	56 9 0·33	9·9193395	
0·37158	High Wilhays	99 12 15·59	1·04	0·49	0·78	99 12 14·32	0·0056278	
0·36877	Sum . =	180 0 6·04	7·82	Ryder's H. to H. Wilhays =			4·8518106	16, 18.
″	180°+ E. =	180 0 2·34		Brown Willy to „ =			5·1510041	11, 13.
=2·34	Error . =	+3·70						

TABLE V.—ARITHMETICAL COMPLEMENT of the LOGARITHMS of the NUMBER of FEET in a SECOND of a GREAT CIRCLE of the EARTH for CONVERTING FEET into SECONDS of ARC on the SPHEROID, and CONVERSELY.

—	On the Meridian.	Perpendicular to the Meridian.	Inclined 45° to the Meridian.	—	—
Latitude.	Log. $\frac{1}{\mu}$.	Log. $\frac{1}{\bar{\omega}}$.	Log. $\frac{1}{\omega}$	Log. $\frac{1}{\epsilon_o}$.	Latitude.
θ	7.	7.	7.	0.	θ
49°	994·21323	992·95977	993·58650	371·71787	49°
10′	·20067	·95558	·57812	·70112	10′
20′	·18812	·95140	·56967	·68439	20′
30′	·17558	·94722	·56140	·66767	30′
40′	·16305	·94304	·55305	·65097	40′
50′	·15054	·93887	·54470	·63428	50′
50°	994·13803	992·93470	993·53637	371·61761	50°
10′	·12554	·93054	·52804	·60095	10′
20′	·11306	·92638	·51972	·58432	20′
30′	·10060	·92222	·51141	·56770	30′
40′	·08815	·91807	·50311	·55109	40′
50′	·07571	·91393	·49482	·53451	50′
51°	994·06329	992·90979	993·48654	371·51795	51°
10′	·05088	·90565	·47827	·50141	10′
20′	·03849	·90152	·47001	·48489	20′
30′	·02612	·89740	·47176	·46839	30′
40′	·01376	·89328	·45352	·45191	40′
50′	·00142	·88916	·44529	·43545	50′
52°	993·98909	992·88506	993·43707	371·41902	52°
10′	·97679	·88095	·42887	·40261	10′
20′	·96450	·87686	·42068	·38622	20′
30′	·95223	·87277	·41250	·36986	30′
40′	·93997	·86868	·40433	·35353	40′
50′	·92774	·86460	·39617	·33722	50′

Note.—Log. $\frac{1}{\mu}$ = arithmetical complement of log. on the meridian.

Log. $\frac{1}{\bar{\omega}}$ = " " perpendicular to the meridian.

Log. $\frac{1}{\omega}$ = " " inclined 45° " "

Log. ϵ_o = log. 2 ν^2 sin 1″ in formula for S.E.

(*Students' Paper, No. 188.*)

"The Gauging of Flowing Water."[1]

By Henry Tudsbury Turner, Stud. Inst. C.E.

The degree of precision with which flowing water can be measured, is not such as to suggest an inference that the science of hydro-dynamics is in a highly satisfactory state. Yet, in the practical questions into which these measurements enter as factors, this inaccuracy is small in comparison with the uncertainty regarding the other physical phenomena, which equally affect their solution. It is the Author's object briefly to review the methods used by engineers to estimate this important quantity.

The two general conditions under which water has to be gauged are:—

First, when flowing from a state of rest in a pond through an artificial notch.

Secondly, when flowing in rivers where the stream is greatly disturbed owing to the roughness of the bed.

The unit of measurement commonly employed is the cubic foot discharged per second of time, though for convenience results are often expressed in such derived units as "million gallons per twenty-four hours."

Notch-gauging, the commonest of all methods of measurement, from the simplicity of the apparatus, observation, and calculation necessary, is applied to ascertaining the flow from a still pond or reservoir, the dimensions of which must be so large relatively to the volume being discharged by the notch, that the water in the neighbourhood of the exit may be in a sensibly statical condition.

The form of overfall notch is either rectangular or V-shaped. The plate, usually of metal, which forms the edge of the notch, should be 3 or 4 inches wide, smooth on the up-stream face, and bevelled away at the edges on the down-stream face, so as to present a fairly sharp edge to the flowing stream. The weir, in which the plate is fixed vertically, and on the up-stream side,

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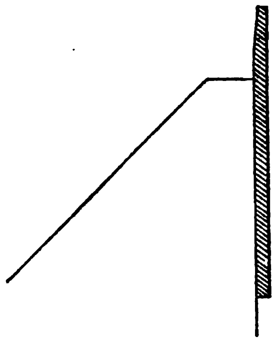
[1] This communication was read at a meeting of Students on the 27th of February, 1885.

should extend beyond each end of the notch for a distance not less than three times the greatest height of water proposed to be passed over the notch sill, and the depth of water below the sill should also not be less than this. Another important feature is that the surface of the pond on the down-stream side of the notch, into which the water discharges, should be sufficiently below the sill to avoid reduction of the atmospheric pressure on the under side of the stream, through the closing in of the ends and exhausting action of the flowing water. Fig. 1 shows an example of such a notch-sill. The above precautions are essential to accurate notch-gauging, to ensure uniformity of the flow. For its estimation by this method depends mainly upon the results of previous experiment made under such conditions, and it is therefore necessary to observe similarity of conditions in the practical cases to which these results are to be applied.

FIG. 1.



$\frac{1}{4}$ full size.

OVERFALL NOTCH, LIVERPOOL WATERWORKS.

The rectangular form of notch is used for measuring a fairly constant flow, and the V notch for small and variable flows. In both cases the discharge is the product of the area of the stream in the plane of the notch into its mean velocity past that plane: or Q = AV.

For the rectangular notch, the ordinary expression for Q, the rate of discharge in cubic feet per second, is

$$Q = C\, l\, h^{\frac{3}{2}},$$

Where l is the length of notch;
„ h is the height of still-water surface above the notch-sill;
And C is a coefficient determined by experiment.

The truth of the expression depends upon a proper value being assigned to C, to ascertain which many careful experiments have been made. An examination of these shows a striking coincidence in their results when applied to precisely similar conditions, and a general variation of C as $\frac{l}{h}$.

That this coefficient should be some function of $\frac{l}{h}$, would appear

evident from the consideration, that whilst the influence of the ends of the notch, termed end-contractions, upon the discharge depend in some manner upon h, their effect relatively to the total discharge must vary inversely as l. The Author, however, finds but few traces of efforts having been made to practically determine the variation of the coefficient upon this basis.

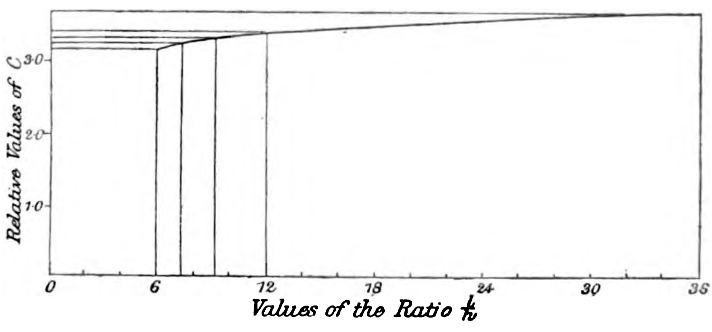
But, although the phenomenon has been noticed both by experimenters and by those who have deduced rules for practical use from their results, it has been customary to obtain from each series of experiments a mean coefficient; and as the investigators have chiefly confined their experiments to short notches, with consequently but a small range in the values of $\frac{l}{h}$, these mean coefficients do not widely differ from one another.

TABLE I.—MEAN COEFFICIENTS of VARIOUS EXPERIMENTERS.

Name.	Mean value of C.
Dubuat	3·38
Eytelwein	3·40
Bidone	3·32
Poncelet and Lesbros	3·23
Brindley and Smeaton	3·41
Blackwell	3·37

Now, although most of the above means do not differ very much from any of the actual values of C in each series, when the ratio $\frac{l}{h}$ becomes much greater than its average value in the experimental

FIG. 2.



cases, a serious error is introduced by taking C constant. This, in fact, amounts to the diminution of discharge owing to end-contraction, repeated as many times as the length of the notch under consideration is a multiple of that of the experimental notch. Fig. 2

shows the variation of C depending on the value of $\frac{l}{h}$ plotted from the experiments of Mr. T. E. Blackwell in 1850.[1]

From the form of the curve it might be inferred, that an extension of the experiments to higher values of $\frac{l}{h}$ would result in higher values of C being obtained; and Mr. Blackwell's other experiments on a 10-feet notch confirm this view. He, however, suggested for practical use the mean value $C = 3\cdot380$ for a 3-feet notch, and $C = 3\cdot570$ for a 10-feet notch.

Mr. Francis, the Author of the "Lowell Hydraulic Experiments," has, in formulating the results of his work, avoided the difficulty of introducing a variable coefficient, by making the effect of end contraction a deduction from the full discharge, dependent only upon h, and specifying that the length of the notch shall be always so great in proportion to the head, that the influence of end-contraction shall not be sensible to a greater distance from either end than to the centre of the flow.

His experiments, carried out in 1853, were on the most extensive and practical scale till then attempted, and every care was taken to make the experimental conditions as nearly as possible those above mentioned as constituting the desiderata of good notch-gauging apparatus.

Mr. Francis' formula, for values of h between 2 feet and 0·5 foot, is

$$Q = 3\cdot33\,(l - n\,0\cdot1\,h)\,h^{\frac{3}{2}},$$

Where n = the number of end contractions. (In the present case two.)

And provided that the ratio $\frac{l}{h}$ never becomes less than 3.

His experiments did not extend to this last-mentioned condition, and the Author questions the propriety of applying the formula to such a low value of $\frac{l}{h}$. In support of this view Fig. 3 has been prepared, which shows the velocity-curve across an 8-feet rectangular notch under a head of 0·5 foot.

The velocities were measured with an accurately-rated electric current-meter, whose fan traversed the plane of the notch, clearing the sill by about $\frac{1}{8}$-inch, and being just covered by the water.

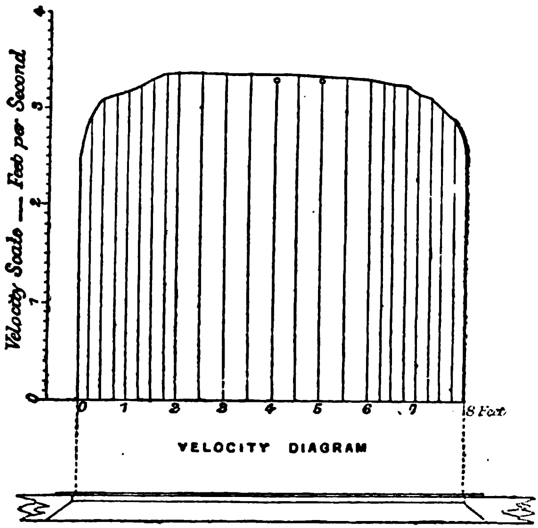
It will be observed that the velocities appear generally higher

[1] Minutes of Proceedings Inst. C.E., vol. x., p. 331.

on the left than on the right of the figure. This is attributable to the assistance received by the fan, which was a left-hand one, from the side-flow near the left end of the notch, and the resistance to turning experienced near the right end, owing to the velocity being greater in the lower than in the upper half of the depth.

But none the less striking is the appearance of diminished velocity near each end of the notch, and it may certainly be taken as extending for a distance of 1·5 foot into the flow from each end. That is, the total length of notch sensibly affected by end contraction under 0·5 foot head is 3 feet, or six times the head.

FIG. 3.



PLAN.

Scale, ¼ Inch to a Foot.

RECTANGULAR NOTCH.

The Author would here draw attention to the "coefficients of efflux" determined by Messrs. Poncelet and Lesbros, which show that the rate of increase of the coefficient diminishes markedly as the value of $\frac{l}{h}$ passes from 5 to 8. And because in every similar notch the conditions of flow are similarly affected, this value $\frac{l}{h} = 6$, as the least allowable, holds for all notches of like character, no matter what value be assigned to h. With these restrictions Francis' formula must be accepted as the most reliable under ordinary practical conditions yet published.

For long notches discharging under small heads, where the value of $\frac{l}{h}$ is greater than 20, there is, excepting Mr. Blackwell's experiments before referred to, no published record of investigation upon the necessary scale to be of use in determining a true expression for discharge.

Comparing Mr. Blackwell's measurement of the discharge over a 10-feet notch under a head of 0·16 foot with that given by the old expression $Q = C\,l\,h^{\frac{3}{2}}$, where the adopted value of C is 3·34, the average of the six mean coefficients before noted, it appears that

Q measured by Blackwell = 2·91 cubic feet per second;

Q by formula $3 \cdot 34\ l\ h^{\frac{3}{2}} = 2 \cdot 34$ " "

That is, the discharge calculated by the formula falls short of the truth by more than 20 per cent. in this instance. And if the notch were longer, the comparison would be still more unfavourable to the formula.

To meet this difficulty the Author suggests an expression derived from the following investigation:—Taking the results of Mr. Francis' experiments upon a 10-feet notch, he reduces them to the discharges of a 3-feet notch under precisely similar conditions of head, and compares these latter quantities with those measured by Mr. Blackwell over a 3-feet notch.

The following Table shows this comparison:—

TABLE II.

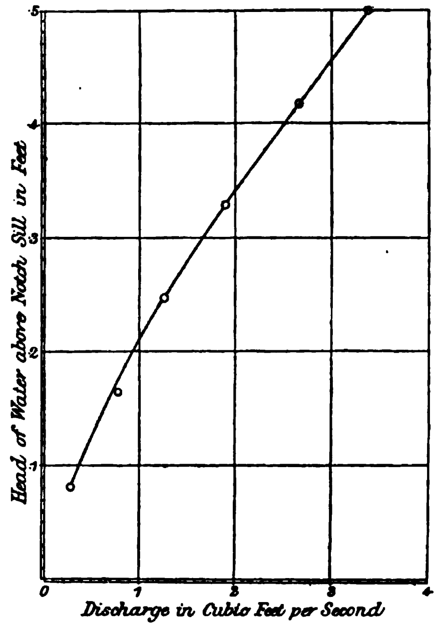
Francis' Experiments.			Reduction to Discharge over 3-feet Notch.			Blackwell's Measurement of Discharge (3-feet Notch).
Length of Notch.	Head.	Q.	Length of Notch.	Head.	Q.	
Feet.	Foot.	Cubic feet per second.	Feet.	Foot.	Cubic feet per second.	Cubic feet per second.
10	1·5	59·30	3	0·45	2·92	2·91
"	1·0	32·60	"	0·30	1·61	1·64
"	0·8	23·40	"	0·24	1·15	1·18
"	0·7	19·20	"	0·21	0·95	0·97
"	0·6	15·30	"	0·18	0·75	0·78
"	0·5	11·70	"	0·15	0·58	0·60

NOTE.—The values of Q in the last column are obtained from the discharge curve, Fig. 4, which is drawn through the points determined by Mr. Blackwell's experiments.

The reduction is effected by multiplying Francis' results by $\left(\frac{3}{10}\right)^{\frac{5}{2}}$, according to the method enunciated by Professor J. Thompson. The close coincidence of the two series of results in the sixth and seventh columns of the Table affords evidence of the accuracy of the gaugings.

Fig. 4 exhibits the curve corresponding with Mr. Blackwell's measurements. It is of parabolic form. Turning to Mr. Blackwell's experiments on a 10-feet notch, the results of which are shown in Fig. 5, by open circles, the positions of certain of them appear erratic. For, all reasoning in hydro-dynamics, supported by the best experiment, goes to show that such a discharge-curve must be parabolic, which would not be the case here were the curve traced through all the experimental points.

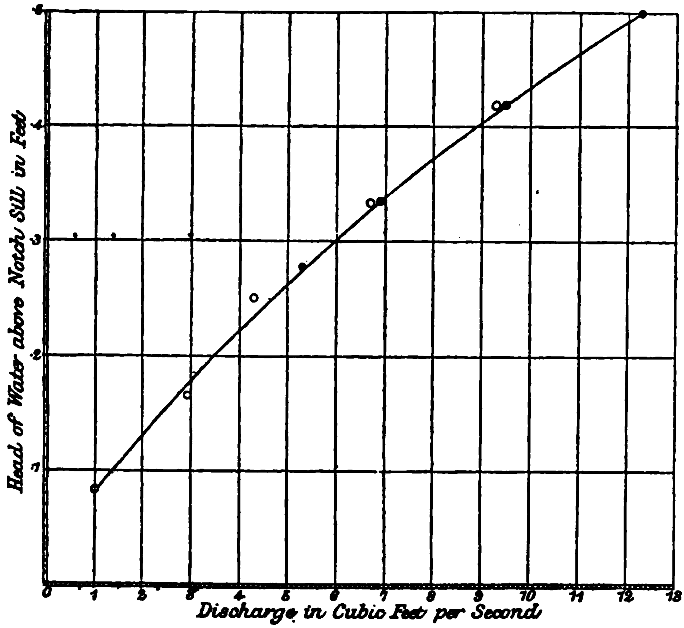
FIG. 4.



3-FEET RECTANGULAR NOTCH. DISCHARGE CURVE.

But applying the method previously noticed, and reasoning from the lower quantities discharged by a 3-feet notch to those which a 10-feet notch would discharge under similar conditions of head, the results obtained enable a very fair discharge-curve to be drawn.

Fig. 5.



10-feet Rectangular Notch. Discharge Curve.

These results are summarised in Table III:—

Table III.

Discharge of a 3-feet Notch, obtained from Equation.		Discharge of a 10-feet Notch under similar Head.		10-feet Notch. Blackwell's Measurement under this Head.	10-feet Notch. Discharge by Formula, D'Aubuisson.	10-feet Notch. Discharge by Formula, Poncelet.
Head.	Q.	Head.	Q.			
Foot.	Cubic feet per second.	Foot.	Cubic feet per second.	Cubic feet per second.	Cubic feet per second.	Cubic feet per second.
..	..	0·083	..	1·04	..	..
..	..	0·16	..	2·92	..	..
0·083	0·260	0·277	5·27	..	..	..
0·100	0·340	0·3	6·89	6·76	..	..
0·125	0·468	0·417	9·49	9·36	..	..
0·150	0·607	0·5	12·29	..	12·31	12·04

Column 4 gives values of Q obtained as described, their positions in the diagram being marked by black dots. Column 5 gives for

comparison the available direct measurements on a 10-feet notch (Blackwell's). Columns 6 and 7 give values of Q under a head of 0·5 foot according to the ordinary formula, using respectively D'Aubuisson's and Poncelet's values of C for this ratio of length to height, being the only other available determinations of the coefficient for so high a ratio.

The equation to the discharge curve in Fig. 4 is:

$$Q = 9{\cdot}13\, h^{\frac{10}{7}} \quad \text{(i.)}$$

And to that in Fig. 5 is very nearly—

$$Q = 33{\cdot}15\, h^{\frac{10}{7}} \quad \text{(ii.)}$$

From the value of Q for any head on the 10-feet notch (up to $h = 0{\cdot}5$ foot) deduct the value of Q for the same head on the 3-feet notch. One-seventh of this difference is the discharge per lineal foot of the middle portion of the 10-feet notch not affected sensibly by end contraction.

Thus Q per lineal foot of notch unaffected by end contraction is,

$$\left(\frac{33{\cdot}15 - 9{\cdot}13}{7}\right) h^{\frac{10}{7}} = 3{\cdot}43\, h^{\frac{10}{7}} \quad \text{(iii.)}$$

Combining (i.) and (iii.), however the length of notch be increased for the low heads under consideration (*i.e.*, h less than 0·5 foot), and when l is not less than 3 feet,

$$Q = (l - 3)\ 3{\cdot}43\, h^{\frac{10}{7}} \times 9{\cdot}13\, h^{\frac{10}{7}},$$

cubic feet discharged per second,

$$- 3{\cdot}43\ (l - 0{\cdot}34)\, h^{\frac{10}{7}}.$$

As evidence of the accuracy of the formula the Author submits the results of three experiments on an 8-feet notch in Table IV:—

TABLE IV.

Head.	Measured Discharge over an 8-feet Overfall Notch.	By Formula. $Q=3{\cdot}43\,(l-0{\cdot}34)\,h^{\frac{10}{7}}$.	By Formula. $Q=3{\cdot}34\, l h^{\frac{3}{2}}$.
Foot.	Cubic feet per second.	Cubic feet per second.	Cubic feet per second.
0·563	11·33	11·56	11·29
0·5	9·87	9·88	9·43
0·354	6·09	5·96	5·64

Column 4 shows the deficiency caused by the use of the mean coefficient in this case of high values of $\frac{l}{h}$.

The Author regrets his inability to extend the comparison to lower values of h, but the object for which the experiments were made did not allow of this. The same feature of error in defect, through the use of a mean coefficient, increasing with the value of $\frac{l}{h}$, is, however, noticeable here as previously, and cannot be far short of 20 per cent. when $h = 0 \cdot 2$ foot.

The quantities discharged were computed from velocity observations made in a straight and uniform brick channel, that carries the water from the Lower Rivington reservoir to the still pond above the notch. An accurately-rated electric current-meter was used, and each experiment comprised a series of twenty velocity measurements in a cross-section of about 13 square feet. The readings of the meter were taken twice at each point, and before commencing a series it was ascertained that the condition of the channel and pond was permanent.

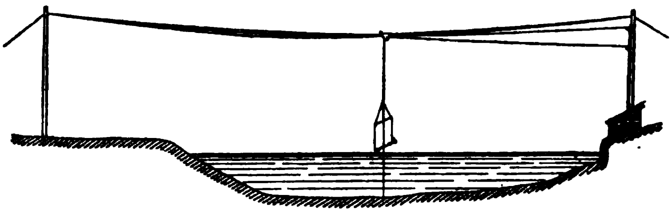
Gauging with the V notch is not attended with the difficulties in computation attached to the rectangular form, and an accurate expression for the discharge is a matter of ordinary hydraulics.

As an example of the most modern method of accurate river-gauging, the Author will briefly describe the operation of gauging the flow of the River Severn, undertaken in the early part of 1880 in connection with the Liverpool Water Act of that year, for obtaining a new supply from the river Vyrnwy, a tributary of the Severn, in North Wales. The site selected was at a point about 1 mile above the Diglis Weir at Worcester, on a straight reach ½ mile in length. The river is here 180 feet wide, and when bank-full is about 25 feet deep in the middle. The section having been accurately levelled, two staffs were fixed on opposite sides of the river with their zero points at the level of the lowest dry-weather flow, and the discharges corresponding with different readings of these staff-gauges were computed from velocity measurements made at each foot of depth below the water surface, past verticals 10 or 20 feet apart in the cross-section. These measurements were made with two of Mr. Deacon's electric current-meters, which before being used, had been rated by Mr. Froude at the Admiralty Testing-Works, Torquay. The details of the construction and rating of these instruments have been previously explained.[1]

[1] Minutes of Proceedings Inst. C.E., vol. lxix., p. 397.

Fig. 6 is a sketch of the apparatus specially constructed for directing the meters to any position in the river section. It consisted of two upright poles, 50 feet in height, placed 240 feet apart on opposite sides of the river. Between these poles was stretched tightly a No. 12 steel wire, upon which traversed a small carriage mounted on two 3-inch pulleys; the carriage was moved forwards or backwards by an endless wire passing round pulleys at the head of each pole, and wound upon rollers at the foot of the pole on the east bank. From this carriage was suspended, firmly attached to it by means of jaws, a T-shaped frame of ½-inch iron piping pointing up and down stream, and carrying, at each extremity of the T-piece, pulleys, over which passed two other wires attached to a lower bar of the same length as the T-piece. These wires were led over a pulley in the carriage to a roller similar to those previously mentioned. The diameters of the rollers were suitably arranged for paying out standard lengths of wire for a given number of

FIG. 6.



RIVER SEVERN. SECTION OF RIVER SHOWING GAUGING TACKLE.

turns. The lower bar carried on its up-stream end a socket into which was fixed a short upright rod, and upon this the current-meters were securely clamped, and by means of the above gear they could be brought into any position in the cross-section.

A fourth wire passed over a pulley in the carriage, down the inside of the stem of the T, and through the lower bar, and was attached to a cast-iron anchor-plate weighing 70 lbs., which rested on the bed of the river. It was armed on the under side with six 3-inch spikes, and its use was to keep the T-frame and lower bar vertically in position during an observation. By means of the last-mentioned wire it was raised when the meters had to be moved on to a fresh vertical. The insulated wires were carried from the meters over the head of the T-frame to a shed where the rollers and electrical apparatus were placed, and in which the operators stood.

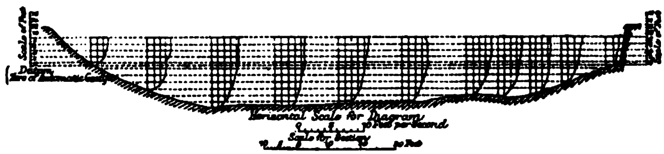
The method of computing the discharge of the river corre-

sponding with any staff-reading was as follows: The observed velocities past each vertical were plotted to a large scale on a diagram, so as to form velocity-curves at each point whose areas represented the discharges past the respective verticals.

The integration of a complete series of such discharges gave the total corresponding rate of discharge. Fig. 7 shows a diagram of one complete series of observations. Both staff-gauges were read regularly throughout each operation, and the mean water-level was carefully determined.

Altogether fifteen series of observations were made, and their results were plotted to a curve. From this curve was constructed a discharge-scale, giving the rate, in million gallons per day, corresponding with the staff-gauge reading, used for computing the

FIG. 7.



RIVER SEVERN. VELOCITY OBSERVATIONS, MARCH 5th, 1880.

daily flow of the river from the diagrams of an automatic gauge. These are drawn by a pen whose zero coincides with that of the staff-gauges before mentioned, and which has been adopted since 1878.

The gauging of the River Vyrnwy, carried out at the same time, was conducted in a similar manner, but to a higher degree of refinement, the velocity measurements being made at each 6 inches of depth past verticals only 2 feet apart.

The Author was engaged in these operations, and he wishes here to acknowledge the kindness of Mr. G. F. Deacon, M. Inst. C.E., who placed the foregoing information at his disposal.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been engraved.

OBITUARY NOTICES.

JAMES AUGUSTUS CALEY was the youngest son of Mr. Philip Caley, a member of an old family that had settled in the Isle of Man for many generations, and an officer in the old Manx Fencibles, in the reign of George III. He was born at Castletown on the 25th of November, 1824, and received his education at the Old Grammar School in that town.. In 1840 he went to Ipswich to study under his brother, Mr. Edward Caley, who was assistant-engineer in sole charge of the construction of the wet-dock at that port, under Mr. Henry Robinson Palmer, the chief-engineer. In 1845 Mr. Caley repaired to Ceylon to join his brother, who, after the completion of the dock, had gone there as a Government engineer, and on his arrival in June of that year, he at once received an appointment in the same department in the Central Province.

On the death of his brother in 1846, he succeeded to the acting appointment of Assistant Commissioner of Roads, in which he was confirmed in 1847 by Earl Grey, upon the very favourable recommendation of the Colonial Government. In 1848, during the rebellion in Ceylon, he called up a division of pioneers, who took possession and defended the main approach to the Kandyan capital. For this service, he received the thanks of Colonel Drought, the Commandant of Kandy, who sent an officer and some men to relieve the pioneers.

Mr. Caley in 1851 took charge of the Civil Engineer's department in the Central Province, and was employed in the construction of roads, buildings, bridges, drainage of towns, irrigation-works, sluices, wells, &c. In 1860 the fine lattice-girder bridge which spans the Mahavile Ganga river, was completed under his superintendence, and for this work, he received official recognition from the late Duke of Newcastle, then Secretary of State, and also, the marked approval of one of the most energetic and able governors of Ceylon,—the late Sir Henry Ward—for the very efficient manner in which the work was carried out. In 1863 he removed to Colombo, where he held the appointment of executive assistant, and was actively employed in various works. In 1866 he retired from the service and received a pension from the Government.

From 1873 to 1882 he held the office of sanitary inspector to the

board of guardians in the district of Bedminster near Bristol, when failing health necessitated his giving up the appointment. His long and active services have been duly recognised, not only by Major Skinner, the Chief Commissioner of Public Works, but also by the Government agents and other prominent officials in Ceylon. His engineering skill, great personal activity, and indefatigable attention to his duties, together with his spotless integrity and honourable conduct, earned for him the highest respect of all who had the pleasure of knowing him.

Mr. Caley was elected a Member on the 5th of December, 1865. He died on the 4th of February, 1885.

AUGUSTUS JOHN DARLING CAMERON, the only son of the late John Cameron, Esq., of Edinburgh and London, was born at Edinburgh, in October 1841, and was educated at the High School and also at the University in that capital.

In 1860 he became a pupil of Mr. John Paterson, and in the course of his pupilage had the advantage of assisting in carrying out extensive town improvements, harbour work, and sewerage and waterworks. He was subsequently engaged by Messrs. Forman and McCall, Consulting Engineers, Glasgow and South-Western Railway, &c., who speak of him as exhibiting much skill in the designing of bridges, especially in the details of iron-work. He was also for three years with Messrs. Wylie and Peddie, as Resident Engineer, in the construction of the eastern portion of the Berwickshire Railway. This firm speak of him thus: "In addition to his good natural talents, as showing great energy of character, and an extensive and varied knowledge of his profession."

For several years he held an appointment of Engineer in the India Office. In 1879 he became Engineer to the South London Tramways Company, and under his superintendence the various lines of that company were constructed, up to the date of his death, which took place on November 27th, 1884, at the age of forty-three.

He was elected an Associate of the Institution on the 27th of May, 1879, and was transferred to the class of Members on the 9th of November, 1880. He was made a Fellow of the Royal Society of Edinburgh 6th June, 1881.

FRANCIS GILES was born at Walton-on-Thames in 1806, and served a regular pupilage to his uncle, Mr. Francis Giles, Member of Council of the Institution. While in his uncle's office he was much engaged in marine-surveying and on dock and harbour works. At the expiration of his pupilage he went to Caraccas on a surveying expedition, and returned to this country after a residence at Caraccas of nearly two years. After this he was engaged on the Mersey and for the New River Waterworks, and then went to the Paris and Lyons Railway, where he remained a district engineer for some time. In the year 1845 he was much engaged in various railway schemes, and in 1851 he went to St. John's, New Brunswick, as engineer-in-chief of the Intercolonial Railway for Messrs. Peto, Brassey, and Betts. While in that country he constructed the railway from St. John to Shediac, and returned to England in 1855. He was latterly engaged in the Dagenham Dock scheme, but retired from active professional life in 1873. Mr. Francis Giles died at Carshalton on the 7th of October, 1884, in his seventy-ninth year. He was elected a Member of the Institution on the 9th of April, 1861.

HENRY JAMES JACKSON (Jackson Bey) was born in the year 1824, and at the age of sixteen entered the works of Messrs. Otway and Warmington, mechanical engineers, to whom he served an apprenticeship of seven years. On completing his indentures he went in 1849 for two years to Sir Joseph Whitworth's works at Manchester. Having by this time attained a thorough acquaintance with the principles and practice of machinery, both in its manufacture and working, he entered the service of the North of Europe Steam-Navigation Company as engineer afloat, and subsequently was similarly occupied for Mr. W. S. Lindsay on a line of steamers to Calcutta and China. For ten years from 1854 Mr. Jackson was associated with the firm of John Penn and Son, Greenwich, in marine-engine work, and through their interest he in 1865 was appointed superintendent of the Egyptian Arsenal at Alexandria, and chief engineer of Khedive Ismail's famous steam-yacht the "Mahroussa," which was accounted the fastest steamer afloat. Leaving Egypt in 1874 Mr. Jackson was appointed superintendent engineer to the General Steam-Navigation Company, having responsible charge of the design and construction of ships and engines for a fleet of sixty-

four steamers, as well as the control of a factory employing five hundred hands. For this work his antecedents peculiarly fitted him, and during his tenure of the post he succeeded in bringing up the company's fleet to a high state of efficiency. He was still in his full career of usefulness, greatly honoured and respected by his fellow officers, when he succumbed to peritonitis on the 2nd of November, 1884, in the sixtieth year of his age. His unexpected death caused sincere regret among his neighbours at Deptford where he resided, and his remains were followed to the grave by a large number of employees and workmen of the company.

He was elected an Associate on the 4th of February, 1873, and transferred to the class of Members on the 14th of January, 1879.

THE HON. JAMES HENRY THOMAS, J.P., Director of Public Works, Commissioner of Railways, Member of the Executive Council and of the Legislative Assembly, Perth, Western Australia, was born in London, March 2, 1826. He was the fourth son of Mr. William Thomas, of Berners Street, Oxford Street, and was educated at the University College School. Having completed his education, he was articled to Messrs. Evans and Sons, mechanical engineers, who were famous for their good work and for making thoroughly efficient workmen. After serving his time, he was appointed to superintend the erection of the gun-machinery manufactured at Messrs. Evans' works, for the arsenal of Trubia, in Spain. Here he was engaged for about two years, and during this time acquired a sound knowledge of the French and Spanish languages. In supervising the erection of the gun-machinery he acquitted himself to the entire satisfaction of the Spanish Government. On his return to England he was selected to be the Engineer to the Imperial Gas-Company's works at Vauxhall, which post he held for several years. This appointment, however, did not offer sufficient scope for his ambition. He accordingly resolved to push his fortune in the colonies, embarking for New South Wales in the ill-fated "Sarah Sands." After remaining in Sydney nearly a twelvemonth, occupied in desultory work, he was appointed in 1853 Engineer to the notable Fitzroy dry-dock, which was hewn out of the solid rock of Cockatoo Island, situated in the centre of Sydney Harbour. In superintending the carrying out of this great work, his natural self-confidence and readiness of resource stood him in good stead; for in colonial works of this magnitude, where recognised appliances are not

always at hand, rough and ready methods have frequently to be devised; moreover, the dock had to be executed by convicts, who had, with considerable difficulty, to be drilled and instructed in their work. More than once his life was in danger from convict machinations. The basin of the great dock was blasted by the usual means, but when the dock entrance had to be cleared below water, other means had to be resorted to. The petards ordered for the purpose had not arrived. A number of oil-cans were therefore collected and roughly converted into torpedoes; with these the mouth of the dock, in spite of adverse predictions, was forced, the Fitzroy dock completed, and the caisson placed ready for the opening ceremony. This work occupied Mr. Thomas until 1857. His next appointment was in the Railway Department of New South Wales, first as Inspector, and finally as Director of all the railway-lines in the colony. In this capacity he had the control of all the trains that conveyed H.R.H. the Duke of Edinburgh to various points in New South Wales. In 1872–3 Mr. Thomas passed some months in England in connection with domestic affairs. Of his voyages from, and back to, Australia, he published on his return to Sydney, a short but interesting account. About twelve or eighteen months after his return to the colony, finding that an engineer was required to carry out extensive works at Perth, Western Australia, he competed for and obtained the appointment under the first administration of his Excellency Sir William Robinson in 1876. He was thus established in what was to prove the most important field of his labours. Here he was successively gazetted Director of Public Works, Commissioner of Railways, justice of the peace, member of the Executive Council and of the Legislative Assembly. His duties were, indeed, manifold; he had to design and superintend the erection of lighthouses, public edifices, and to plan and superintend the carrying out of the railway and telegraph lines. As one of the Commissioners for Western Australia for the English section at the Paris Exhibition of 1878, he had the honour of receiving a medal, accompanied with an autograph letter from and a photograph of H.R.H. the Prince of Wales. But his duties were too onerous, and manifold, even for a constitution such as his. His health gradually gave way; a second voyage to England was had recourse to as a remedial measure; this appeared to have restored him, but on his return to Perth and to his numerous duties his health again broke down. A voyage to Sydney was then tried, and was thought to have thoroughly reinstated him, but it was unavailing. His friends began regretfully to perceive that he was doomed. Still, with his

usual courage, he bravely held on to his duties till he fainted in his place in the Legislative Assembly, whence he was borne to the home he was never again to leave. He died on the 16th July, 1884.

On Mr. Thomas's death becoming known the House immediately adjourned, the Colonial Secretary and the Commissioner for Crown Lands both uttering warm tributes to his memory. On the day of the funeral the public offices were closed, and the hushed aspect of the town testified to the great respect in which he was held.

Mr. Thomas was elected a Member of the Institution on the 14th of January, 1879.

THOMAS PARKER WATSON, the son of George Watson, who held an appointment in the Four Courts, was born at Dublin, on the 4th June, 1828.

His education was commenced at the private grammar school of Doctor Wallis, and in 1846 passed from thence to Trinity College, Dublin, where he obtained a diploma, with a certificate of merit, from the engineering school in December, 1849. In the same year he took his degree of B.A.; and later on that of M.A. of Trinity College. In 1850 he commenced a career for which he afterwards proved himself eminently fitted, and was first engaged on the survey and construction of the Hamburg-Lübeck Railway, serving under Mr. N. Scheffer, a Prussian engineering officer, for about three years. In 1853–1855 he was engaged on the Copenhagen-Korsör Railway, in Denmark, under Mr. W. G. Brounger, M. Inst. C.E., but in the service of Messrs. Fox and Henderson the contractors for the line; being stationed for about two years at Ringstedt, near to which place, the works were heavy, and afterwards holding the appointment of engineer to the Danish Railway Company, under his former chief, Mr. Scheffer, for about one year longer. In September, 1856, he was appointed district engineer at Amstetten, on the Kaiserin-Elizabeth-Westbahn (from Vienna to Linz) under Mr. George Giles, M. Inst. C.E., in the service of Messrs. Peto, Brassey and Betts, the contractors for that section of the line. The works under Mr. Watson's direction were heavy and complicated; but were carried out in a manner which elicited high encomiums from the Austrian engineers.

In 1861 he again went to Denmark, having been appointed to the post of district engineer at Odense, on the eastern section of the Fyen Railway (some 28 miles) from Nyborg on the Great

Belt to Brendekilde. This formed a portion of the system of railways then being carried out by Messrs. Peto, Brassey and Betts, as concessionaries to the Danish Government under the chief direction of Mr. F. J. Rowan. Two large stations were erected on this length, viz., at Nyborg and at Odense. On the opening of this section in September 1865, Mr. Watson was decorated by the King of Denmark, with the order of Ridder af Dannebrog, for the able and satisfactory manner in which the works under his supervision had been executed.

In 1865 he was appointed to another section of the same system of railways in the north of Jutland, and stationed at Aalborg. Returning from Denmark Mr. Watson was next engaged on the Metropolitan and Metropolitan District Railways, still in the service of the same firm, for whom he also conducted some extensive works on the Cornwall Minerals Railway in the years 1872–74.

In 1874 Mr. Watson entered the service of the Cape of Good Hope Government, receiving the appointment of resident engineer on the Midland system of railways, from Port Elizabeth to Graaf-Reinet, a distance of 184 miles. In 1878 he was promoted to the post of chief resident engineer for the eastern province, with the charge of some 400 miles of railway, viz., from Port Elizabeth to Graaf-Reinet, 184 miles, and from Port Elizabeth to Cradock, 182 miles: also the Branch line to Grahamstown, 35 miles.

In 1881–82, the surveys, and eventually the construction, of the railways northwards and westwards, viz., from Cradock to Colesberg, the route for the Orange River, 126 miles; and the connecting line, *viâ* Hanover, to unite the Midland system of railways with the Western system, 68 miles, were also carried out under Mr. Watson's direction, the former being opened in October 1883, the latter in March 1884. In May 1883, Mr. Watson was sent on a confidential service of great importance by the Cape Government to Kimberley, to report technically upon the state of the diamond mines of that place. This duty, although undertaken under the most disadvantageous and delicate circumstances, was performed with tact and completeness, and elicited a warm expression of satisfaction from the Government.

At the close of 1884, all the lines of railways for which Acts of Parliament had been obtained in the Cape Colony having been completed, the engineering staff was broken up, and Mr. Watson was pensioned by the Government. In November he returned to England, after a ten years' residence in the Cape Colony, apparently in the midst of health and strength, full of manly

vigour, and unabated mental energy. He died very suddenly, on the 22nd January, 1885, as was generally supposed from heart disease, probably more or less influenced by the return to an English climate in winter.

Gifted by nature with unusual ability and capacity, he enjoyed all the advantages conferred by education, with a refinement of mind and principles of the highest order. He was possessed of fertility of resource in difficulty, rapidity of thought and clearness of perception, and a habit of keen observation. A kind and feeling heart caused him to be endeared and respected alike by those above him as well as by those who had the privilege and pleasure of serving under him.

The opinion held of him by a high official of the Cape Government, one who by nature and experience was very competent to judge correctly in this matter, was recently so suitably expressed, that it may be appropriate to cite it here.

"No one could exceed Mr. Watson in the interest and attention which he paid to his work, nor was he the mere official, ready to assent to any proposition which might happen to come from above: he had a very distinct individuality, and always defended his own opinion.

"Mr. Watson was particularly good at framing a comprehensive and precise report; one may be remembered, the last indeed which he drew up, on the connection between the Eastern and the Midland systems.

"In 1883, he drew up, at my request, a report on the Kimberley Mine from an engineering point of view. This report was extremely unpalatable to many (interested in the mine), but time has proved the correctness of Mr. Watson's forecaste.

"The news of his sudden death shocked me very much. He is a distinct loss to the colony, and it will be hard to replace him."

Mr. Watson was elected a Member of the Institution on the 13th of January, 1880.

JOSEPH WILLIAM JENKINSON, son of Mr. Joseph Jenkinson, of Chertsey, Surrey, was born on the 9th of January, 1855. At the age of fifteen he entered the works of Messrs. Simpson and Co., of Pimlico, London, where he remained until 1879, taking during the latter years of his stay, and at the early age of twenty-four, a leading part in the design of the various large pumping-engines and other machinery constructed by the firm.

In December, 1879, he went out to Australia to take up an appointment as assistant to Mr. Oswald Brown, M. Inst. C.E., the then hydraulic engineer of the South Australian government. Whilst in the colony, Mr. Jenkinson assisted in designing and executing many works of water-supply, some of which were of a novel nature owing to the peculiarities of the country and climate; among these may be cited the Mount Gambier waterworks, in which the water is obtained from the crater of an extinct volcano.

In October, 1884, Mr. Jenkinson returned to England and proceeded to Pernambuco, to take charge of the construction of large works of water-supply designed by Mr. Brown. Owing to the presence of cholera in France, the steamer in which he sailed was, on arrival, refused admittance to the Port of Pernambuco, and the passengers were therefore taken on to Rio de Janeiro, where all were placed in quarantine. After some days, *pratique* was granted, and Mr. Jenkinson hastened to Pernambuco by the first opportunity; on his arrival there he complained of the effects of exposure to the sun whilst in quarantine, and it is feared he was ill-prepared to withstand the climate. On the 7th of March, 1885, yellow fever declared itself, and he fell a victim to this scourge on the 10th of the same month.

Although but thirty years of age at his death, Mr. Jenkinson had acquired extensive experience of his own branch of the profession, and had proved himself a man of no ordinary ability, combining theoretical attainments with practical skill, both in the design and execution of work.

He was elected an Associate Member on the 5th December, 1882.

JOHN MACGLASHAN, the eldest son of Mr. John Macglashan, of Peterhead, was born on the fifth day of September 1842.

He was educated at the Marischal College, Aberdeen. Selecting the profession of a civil engineer, his studies were directed with that view, and in 1860 he was articled to Messrs. Bell and Miller, MM. Inst. C.E., of Westminster and Glasgow. Early qualifying for a responsible position, he was deputed Assistant-Resident at the New Albert Docks, then under construction at Greenock, under Mr. John Thompson, as Resident Engineer. These works, to some extent of a novel character, attracted the attention of the late Professor Rankine, who became a frequent visitor during their progress. Mr. Macglashan's method, his constant application

and extreme accuracy, did not escape the critical eye of one so well competent to judge as Professor Rankine, who, with great kindliness, recorded his impressions in a complimentary letter of encouragement addressed to the young engineer. Mr. Macglashan acted as Resident in charge of the new Graving Docks constructed for Messrs. Tod and Miller, at Partick. At this time he found leisure to conduct classes of engineering and mechanical drawing at the Glasgow School of Art. In 1865 he was one of six candidates selected from among numerous applicants for the office of Assistant Engineer to the Port of Dublin, but before the appointment was made he accepted an engagement upon the Great Indian Peninsula Railway, offered to him by Messrs. Hood, Winton and Mills, contractors, and proceeded at once to the Central Provinces to take charge of a section of 20 miles of the works then in progress between Hurda and Sohagpore. This step seems to have been the decisive one that influenced and determined his future professional life. After acquitting himself satisfactorily on the contract referred to, upon the works drawing near a close in 1868, he went home, married, and returned at once to India to take up an appointment as Assistant Resident Engineer upon the staff of the Railway Company.

In February 1869, he was placed in charge of the construction of 35 miles of single line it was intended to double, including the reconstruction of an important viaduct over the Wághoor river. After the completion of these works, he directed the maintenance of a district of 200 miles in length, and, later, the reconstruction of important bridges and viaducts upon 83 miles of the Nagpore extension. The summer of 1874 in India was an unusually hot one; works were pushed on upon the "re-construction" with concentrated energy, as the building-season drew near its close, and the annual rains and floods approached, entailing more than ordinarily severe exposure. In Mr. Macglashan's case it unfortunately led to his prostration by sunstroke, seriously affecting his health at the time, and in its after-consequences aggravating into a chronic form an ailment—asthma—symptoms of which had sometimes shown themselves. After the completion of the reconstructions upon the Nagpore branch-line, Mr. Macglashan was transferred, in 1876, to the district between Sholapore and Raichore.

In the famine year of 1878, the sudden and general failure of the water-supply upon the district referred to and adjacent to it, threatened to interfere most seriously with the traffic of the railway; it was only by the most energetic and unwearying efforts of

the engineers and their principal subordinates, that the danger was averted. In this work Mr. Macglashan elicited the warm commendation of the Engineer-in-Chief, and was afterwards deemed worthy of the special thanks of the Board of Directors in London. It was then hoped that his health would become re-established; for taking advantage of the privileges of his service as to leave-of-absence, he twice visited Australia, and once the hill-districts of Ceylon, deriving considerable benefit at the time from the change. Mr. Macglashan's next and last position, from 1881–83, was on the Dond and Munmar line, with a residence at Ahmednuggar; it was a special appointment, with sole charge of the district, immediately under the Chief Engineer, Mr. Wilson Bell, M. Inst. C.E., and probably kindly directed with special reference to the climatic advantages it afforded. With lapse of time, however, no amelioration of his malady was perceptible, and it needed the courage and firmness of will conspicuous in Mr. Macglashan's character, to make it possible for him not only to remain at his post, but to continue to discharge his duties ably and energetically. In May 1883 he went home on furlough, when it was hoped his native air might prove beneficial. There was an apparent rally during the fine summer of 1884, but unhappily a relapse occurred, and he died September the 23rd, in the forty-second year of his age, at Aboyne, Deeside.

Mr. John Macglashan's personal characteristics were, a singular unselfishness, a kindness of heart, and an affectionate disposition, endearing him not only to his family circle, but to many outside it. He conducted his business-intercourse with others in a way that avoided exciting friction; and though emphatically "a man without guile," yet more than a match for the guileful man whom he encountered in business; with all the characteristic shrewdness of his nation, and keenly alive to the interests of the service to which he belonged.

He was elected an Associate Member on the 23rd of September 1875.

JOHN NAPIER, eighth and youngest son of the late David Napier, engineer, Lambeth, was born in London on the 29th October, 1832. He was educated at the High School, Glasgow, and King's College School, London. After completing his education he proceeded to New Zealand and was for some time engaged in land-surveying. Having decided to follow the profession of a civil engineer he returned to England and entered the office of

Messrs. Walker, Burges and Cooper, in April, 1856. He was at once placed under the resident engineer on the Netherton Tunnel branch of the Birmingham Canal-Navigation, then in course of construction, where he was engaged for about two years; on the completion of these works he returned to Messrs. Walker and Co.'s office in London, where he remained as an assistant till March, 1865, when he was appointed principal assistant to Mr. Thomas Ormiston, then chief engineer to the Elphinstone Land and Press Company, Bombay.

He arrived in Bombay on the 11th May, 1865, and was for three years engaged on extensive works of reclamation from the harbour with tidal-basins, bridges over the railways to connect the estate with the native town and other works; during six months of this time he had the entire charge of the works in Mr. Ormiston's absence in England, and his services were substantially acknowledged by the directors and the chief engineer. The state of Mr. Napier's health necessitated his going home at the end of his engagement. He therefore left Bombay on the 7th July, 1868, and returned to London. Here he remained for some years in delicate health and occupied himself with sundry inventions, some of which he ultimately patented. He determined again to visit New Zealand, principally for the benefit of his health, and left London on the 6th May, 1874. After residing for some time there he proceeded to Australia and was engaged in railway engineering in New South Wales. His expectations of recovery in the colony were not realized, and he died at Sydney in August, 1883. Mr. Napier inherited some of his father's mechanical ability and was very fond of his profession, but was prevented by his delicate health and retiring disposition from engaging in the active practice of it.

He was elected an Associate Member on the 2nd of May, 1865.

FRANCIS WILLIAM OTTER was the third son of the Ven. William Bruere Otter, Archdeacon of Lewes, and was born on January 8th, 1847. His education was mainly private, but he was for a short time a student at King's College, London. He became a pupil of Mr. Peter Barlow, M. Inst. C.E., and assisted in the construction of the railway bridge over the river Lea, at Bow.

In 1873 he was, together with Mr. McNair and Mr. Allen, appointed to survey and build a railway from Teheran to Reshd,

under a concession from the Shah of Persia to Baron de Reuter. When the line had been surveyed and a small part of it built, the concession was suddenly withdrawn, and the engineers returned to England.

From 1875 to 1878 Mr. Otter was engaged in the construction of a railway from Worcester in the Cape Colony, under the Colonial Government.

Mr. Otter was elected an Associate Member on the 3rd of December, 1872. He had not practised the profession for some years previous to his death, which occurred on the 1st of January, 1885.

JOHN PRENTIS HAWLEY, eldest son of the late Mr. William Hawley of Fleet Hall, Hockley, near Rochford, Essex, was born on the 7th of May, 1818. He entered the service of the Lambeth Waterworks Company in 1841, having been engaged by the late Mr. James Simpson, Past-President Inst. C.E., as outdoor District Manager. His occupation was to look after the supply of water generally, including the laying of service-pipes, the connecting of the houses, the quality of fittings, and the management of the turncocks and other outdoor men. When at Brixton his official residence was near the Works there, which after the new supply was introduced rapidly increased in size. He was also storekeeper at that station, and attended to the rating of the houses and the general supervision of the concern under Mr. Simpson. On Mr. Simpson's death Mr. Hawley continued in the same position under his successor, Mr. John Taylor, M. Inst. C.E. The latter gentleman having been acquainted with the Lambeth Works since 1837, when he first joined Mr. Simpson, was much associated with Mr. Hawley during his entire term of service, and bears testimony to the esteem in which he was held from his constant attention and assiduity in the position he occupied. The continual extensions of the district were under Mr. Hawley's supervision, and a high opinion was entertained by his chiefs of his judgment in the management of his department.

Mr. Hawley's occupation being one of almost unvaried routine but little opportunity occurred for the display of professional acquirements; but he invented (1869) and patented improvements in apparatus for controlling the flow of water under great pressure, to regulate constant supply and to prevent waste. Also a double-screw stop-cock which can be made to control very effectually water or steam under high pressure. After a service of forty-one years

to the Lambeth Waterworks Company, Mr. Hawley retired on a pension in 1881. He died suddenly on the 21st of January, 1885, He was elected an Associate on the 7th of May, 1872.

MAJOR-GENERAL JULIUS GEORGE MEDLEY, R.E.,[1] was born on the 19th of July, 1829. Having chosen an Indian career, he was gazetted on the 11th of June, 1847, and arrived in India on the 12th of March, 1849, joining the Public Works Department as Assistant Engineer in June 1850. In the course of a thirty-five years' service in the East, General Medley took personal part in many stirring events, which render the story of his career one of more than ordinary interest. Though mainly employed as an officer of the Public Works Department, his official "record" largely embraces military duty and service in the field. On Medley's first arrival in India Lord Dalhousie had been a year in office, and the second Sikh war had just resulted in the annexation of the Punjab. In those days India was still reached by a three months' voyage round the Cape, and its vast provinces had generally to be traversed by *palki*. As yet the country was innocent of railways, although the subject of improved communications had seriously occupied the attention of the Government, and within a few years the first tentative contributions were taken to the construction of a system of railways and telegraphs. It was not till 1853 that the first Indian railway—the line between Bombay and Tanna—was opened, and by that time the zeal and energy of O'Shaughnessey had established the main lines of telegraph which proved of such vital importance in the critical period that shortly followed. Nothing could better illustrate the silent but rapid growth of modern institutions in India—and the advancement in civilization which that growth implies—than the eloquent fact that the young engineer who found the country without railways, even in the neighbourhood of its capitals and commercial centres, left it at the close of his career covered with a vast network of communications reaching to its remotest corners. The achievements of the Government during the past thirty years in this field of activity are such as might stir the pride of any nation, and certain events may be pointed to as closely linking General Medley's name with the history of railway development in India. During his service as

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[1] The substance of this memoir has been taken from the *Pioneer*, Allahabad, July 24, 1884.

Consulting Engineer for Railways at Lahore, the Punjab Northern Railway has been completed to Peshawar and Kushalgarh; the Indus Valley Railway has been opened, giving the Punjab through connection with the sea at Karachi; while the construction of the Sibi Railway also comes within the period in question. General Medley was largely instrumental in pushing on all these works.

General Medley's career might be regarded indeed as a notable one, if only for the fact that it synchronises with an important era of railway construction in India. For only a portion of his service, however, was General Medley directly connected with railways. His war-services alone will give him a distinct position in Indian history for all time. As Field Engineer, he served with the force under Brigadier Chamberlain against the Bozdars, on the lower Derajat frontiers, in 1857. This was a stiff piece of hill-fighting, and hardly was the expedition over when rumours began to find their way to far Dera-Ghazi Khan of the evil deeds which heralded the Mutiny. Private letters and the newspapers from Lahore brought ominous news which was not always believed. "The idea of a general rising," General Medley has written, "even among the Poorbeah army, was at that time looked upon as absurd, and the frontier officers at any rate looked with confidence to their splendid regiments, who had fought against men of their own colour and faith during the last eight years." But the day of terror had dawned, and in the sudden rush of events, General Medley shortly found himself acting as Field Engineer with the army before Delhi. In a spirited little work entitled "A Year's Campaigning in India," published in 1858, he has given a graphic account of the events in which he himself took a distinguished part. Some of the incidents of the Delhi siege, as told in this work, are among the most vivid and faithful reminiscences of the time.

The historical service which General Medley rendered at Delhi was the reconnoitring of the main breach the night before the assault, and the leading of the first column to the attack on the following morning. He has told the story of the assault simply and modestly. There was a delay, and the advance was made in daylight. "Forming the ladders into a sort of line, we rushed towards the breach, closely followed by the storming party, and in a minute found ourselves on the edge of the ditch. But so terrific was the fire from the breach and the broken parapet walls, that it was at first impossible to get the ladders down into the ditch, which was necessary to enable us to ascend the masonry escarp below the breach. Man after man was struck down, and the

enemy, with yells and curses, kept up a terrific fire, even catching up stones from the breach in their fury, and dashing them down, dared us to come on. At this moment I felt a shock, like a blow, on my right arm, which made me stagger, and then I knew I was wounded. The excitement was, however, too great for pain to be felt, and I knew that the bone had escaped, so that it could not much matter, ... As soon as I saw my first ladder down I got down into the ditch, mounted up the escarp, and scrambled up the breach, followed by the soldiers." Immediately after the capture of Delhi he was appointed Garrison-Engineer of the Imperial city, but never took up the appointment, as much stern work had yet to be done. He had been severely wounded, but was soon well again, and served with Sir Thomas Seaton's force in the Doab, being present at the affairs of Khasgunge and Putteatec. Early in 1858 he joined Outram, and acted as directing Field-Engineer with the army under the Commander-in-Chief during the final siege of Lucknow. Here again, after the capture, General Medley was appointed Garrison-Engineer, and his first work was to clear away the houses round the fort, and, regardless of ownership, to cut three broad streets at angles from the fort and through the heart of the city. These were the days of rapid promotion, if not of lavish decoration. General Medley entered the campaign as a lieutenant, and while below the walls of Lucknow, he was made Captain one day and Brevet-Major the next. Beyond this he added to the medal for the North-West Frontier, the Mutiny-medal and two clasps, and the mention of his service in the Delhi and Lucknow despatches. Subsequently, he attained the full rank of Colonel in 1881, and that of Major-General in January 1884.

General Medley held various important civil appointments. He was Deputy Consulting Engineer for Railways at Lahore in 1858–60, then Principal of the Civil Engineering College, Calcutta, and subsequently officiated as Under-Secretary to Government in the Public Works Department. He was Principal of the Roorkee College, from 1863 to 1871, and his name will long be honourably remembered in connection with that institution. Here he compiled an excellent "Manual of Engineering" for the use of the students, which is now adopted far and wide throughout India. He also started the "Professional Papers on Indian Engineering." From Roorkee, General Medley went to Lahore, first as Superintending Engineer, and then as Consulting Engineer for Guaranteed Railways. During his eight years' tenure of the latter office he saw the carrying capacity of the Sind, Punjab, and Delhi railway increased at least 50 per cent. by means of

extensions, improvements, the addition of new stations, and the increase of rolling-stock. By the opening of the Punjab Northern and the Indus Valley Railways the sphere of General Medley's responsibility was greatly extended, and this occurred at the time of the Afghan War, which threw such a sudden stress of traffic on the lines.

The efficiency of the transport at this period was in a great degree due to the manner in which General Medley urged on the construction of the frontier lines; and when it is considered that the lines were thrown open long before the work of construction was nearly finished, and that the difficulties were further augmented by paucity of rolling-stock, the result must be regarded as most creditable to all concerned. At the close of the war, the control of the two State lines was transferred to the Director-General of Railways, and the Consulting Engineer has since only acted as Inspecting Officer for these lines. Still, General Medley continued to exercise control, more or less, over upwards of 2000 miles of railway, and he witnessed an extension of the lines of Northern India at the rate of 200 miles a year, for the past seven years.

With regard to the large schemes of railway extension which have lately been occupying so much attention, his opinion was that it would be a wiser course to develop the system of feeder-lines, rather than to launch out into a number of altogether fresh enterprises. This is doubtless a matter on which there is difference of opinion; but there is one ground of common faith on which all who have known General Medley will readily unite—the recognition of the unfailing courtesy, kindliness, and chivalry which he showed in the course of his ordinary duties, or in the conduct of reforming controversy. The position of a Consulting Engineer is one of great difficulty; his large powers of control are only loosely defined. The guarantee-system involves double government and divided responsibility, and it is only by means of compromise that the work can be carried on at all, where differences of opinion are certain to rise. It is therefore to the honour alike of General Medley and of the authorities of the Sind, Punjab, and Delhi Railway that the arduous work in this case has been accomplished smoothly and in a spirit of entire friendliness. To General Medley's many friends it would indeed have been strange had it been otherwise. Genial, cultured, enthusiastic, hospitable, General Medley retired full of life and vigour, and it was not too much to hope that his Indian career might yet have its counterpart in England, where his special

knowledge, wide experience and literary gifts, would no doubt have been highly esteemed. These justifiable hopes were however not destined to be fulfilled, for his career was suddenly cut short at Port Said, on board the P. & O. steamer *Ravenna*, homeward bound, on the 28th of August, 1884, when he was only fifty-five years of age. General Medley was elected an Associate of the Institution on the 28th of May, 1861, holding at that time the rank of Major.

WALTER NEILSON[1] was the son of John Neilson, of Oakbank Foundry, Glasgow, a throughly proficient millwright and engineer; and he was a nephew of James Beaumont Neilson, M. Inst. C.E., whose name will ever be closely identified with one of the greatest inventions in the manufacture of iron, that of the hot blast in the smelting of iron in the blast furnace. He was also a brother of the late Mr. William Neilson, of Mossend Iron and Steel Works. Walter Neilson was born in March 1807, and after spending some time in the University of Glasgow, went into the works of his father and passed through all the branches of the mechanical engineer's calling as it was then practised; and by the time that he had attained his majority he was installed in the management of the works. Mr. Neilson became an accomplished engineer, and was familiar with many excellent devices for economising labour, and for producing mechanical structures of great efficiency. It was during his connection with his father's works that the *Fairy Queen* was turned out, a vessel which was one of the earliest iron steamers built in Scotland, and it is worthy of note that she was fitted with oscillating engines, which were probably the first engines of the kind ever employed in a steamboat. The same establishment turned out general engineering work in great variety, together with pumping and winding machinery for collieries, blowing engines for blast furnaces, &c. In the year 1836, Mr. Neilson's services as an all-round practical engineer were called into requisition for the management of a new blast-furnace establishment, that of Summerlee, Coatbridge. He was the junior partner in the firm formed to start the works, and the other members of the firm were his father (Mr. John Neilson), and Messrs. George and John Wilson, of Dalmarnock and the Hurlet

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[1] This notice has been abridged, with some additions, from one in the *Iron and Coal Trades Review*, August 29, 1884.

Alum Works. The firm, which was long known as Wilsons and Co., ceased about fifteen years ago, and the works have since been owned by the Summerlee Iron Company, consisting of the deceased Walter Neilson, his brother Hugh Neilson, and Messrs. John and William Neilson, sons of the former; and the active manager for a number of years has been Mr. George Neilson, another son. At first the works were commenced with two blast-furnaces, the blowing-engine for which was made at Oakbank Foundry. From time to time the works were extended until they eventually embraced eight furnaces, all of which have been so much improved that they now bear very favourable comparison with the most efficient blast-furnaces in Scotland. It was the constant aim of the deceased to adopt every new improvement in blast-furnace practice that was certain to increase the yield of pig iron, and improve its quality, and economise the fuel required in its production. Many years ago, he made experiments with the view of taking off the so-called waste gases of the blast-furnace. In the year 1868, he was successful in adapting the Addenbrook system of collecting a portion of the combustible gas and turning it to account in heating the air of the blast, and in getting up steam. Further progress was subsequently made in the way of adopting other scientific appliances about the furnaces. Up till the present, three furnaces have been adapted to the Addenbrook system, with open tops, and four have been closed in at the top and are worked on the bell and cone system, in much the same way as many of the furnaces in the Cleveland district. The Summerlee Iron Company, guided by the excellent business tact of the late Mr. Neilson, now own coal and ironstone mines in four or five different counties, the chief supplies of minerals, however, being obtained from pits in Lanarkshire. They have long devoted much attention to the production of hæmatite pig iron, on which they have at present two blast-furnaces employed. During the past seven or eight years they had in almost constant use the steamer named the *Summerlee*, bringing hæmatite ironstone from the mines in Spain. The Summerlee Iron Company have also a large trade in coals, amounting to about 5,000 tons per week. Two or three years ago, the company determined to carry out a course of experiments with the view of collecting and utilizing the ammonia contained in the gases emitted from the blast-furnaces, and the experiments were attended with such an amount of success that the production of sulphate of ammonia has now become a regular branch of the company's business. After the death of his brother William Mr.

Walter Neilson became the senior partner in the Mossend Iron and Steel Company. He took the liveliest interest in the welfare of his workpeople, by whom he was generally and sincerely respected, as also by his many business and personal friends. Though of a very quiet and retiring disposition Mr. Neilson was a very genial companion, and withal a high-minded gentleman. He rarely mixed in public affairs in any way, but from the very first he took an exceedingly keen interest in the welfare of the Iron and Steel Institute, and did not hesitate to travel great distances to attends its meetings. Mr. Neilson was predeceased by his wife, but he is survived by a family of four sons and three daughters.

Mr. Walter Neilson was elected an Associate on the 5th of May 1868. He died on the 18th of August 1884.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Measurement by Pacing in Aneroid-Surveys. By Dr. W. Jordan.

(Zeitschrift für Vermessungswesen, vol. xiii., 1884, p. 485.)

The Author here recommends the adoption of pacing in conjunction with aneroid-readings, for the more speedy construction of plans of hilly country, especially if based on a reliable map, with a few fixed altitudes marked on it. Two plans of undulating country were made by him, one with a tachymeter, the other by pacing in conjunction with an aneroid, the latter containing thirty-five stations, with a total length of traverse of 1218 metres, and elevation of 168 metres. The error in the barometrical measurements, after the first and last altitudes had been adjusted, averaged uphill and down hill, from 1 to 2 metres, and still averaged 1 metre per station after adding together the rises and falls. Pacing on level ground can be made to within from 2 to 3 per cent. of the truth; but on slopes it is irregular, and on a rise of 30° only attains to half that accuracy. From comparing his pacing with the plan made by the tachymeter, the Author framed the following Table:—

	Rising Ground.	Falling Ground.
Gradient 0° . . .	1 pace = 77 centimetres.	1 pace = 77 centimetres.
" 5° . . .	" = 70 "	" = 74 "
" 10° . . .	" = 62 "	" = 72 "
" 15° . . .	" = 56 "	" = 70 "
" 20° . . .	" = 50 "	" = 67 "
" 25° . . .	" = 45 "	" = 60 "
" 30° . . .	" = 38 "	" = 50 "

As the horizontal projection of the section must be given in metres, 100 paces on a gradient of 30° on rising ground are plotted as 38 metres, and down hill as 50 metres respectively.

In aneroid measurements, the gradient of the uphill or down-hill pacing is found indirectly from the difference in the aneroid readings at beginning and end of a section, which can be changed into metre differences of altitude sufficiently accurately by multiplication with the constant 11·5; the horizontal projection of the gradient can then be found.

Two Tables are given by the Author for the reduction to metres of his uphill and down-hill pacing, through barometrical differences,

ranging from 0·0 millimetre to −1·6 millimetre in the case of rises, and to + 2·4 millimetres in the case of falls, and these he asserts are within 5 per cent. of the truth. An extract of his work is also given, reduced by these very Tables, showing that in eleven stations, comprising a length of 312 metres traversed, the horizontal section computed was only about 8 per cent. too long.

E. H. C.

Signals for Polygon-Surveying. By Dr. W. JORDAN.

(Zeitschrift für Vermessungswesen, vol. xiii., 1884, p. 520.)

Although it is an axiom in surveying that polygon-lines must be as long as possible, still cases arise, as in town-surveys, where short lines are unavoidable. Special care is then necessary to reduce as far as possible the errors caused by eccentricity either of the theodolite or the signal. With this object the Author successfully used the signal here described, which consists of an iron telescopic rod, drawing vertically out from the centre of a tripod furnished with levelling-screws resting in little cups. The verticality of the rod is ensured by a box-level, while its pointed lower end assists its correct centering over any point either on a stand or on the ground. The observing of a polygon A B C D E is thus carried out:—Three stands of similar construction (as regards the upper plate) are set up accurately to within 1 centimetre over points A, B, C, the theodolite being placed upon the stand over B, and two of the above signals on the stands over A and C. After the angles are taken, the two stands over B and C are left, while that over A is removed to D. The theodolite is then moved to stand C, while the two signals are set up over B and D. In this procedure everything consequently depends upon the centering to within 1 millimetre of each instrument successively over the exact spot occupied by the preceding one, and this is best ensured by having tripods of one pattern for both theodolite and signals, as then the little cups can be left undisturbed on the heads of the stands while the instruments are being exchanged. Whether the tripods are themselves accurately centred can be found by observation. Where the theodolite and signals have tripods of different pattern, the Author has used three brass grooves, radiating at angles of about 120°, in which the tripod points were inserted. Polygon observations on the above principle can be carried on very rapidly and smoothly. In town-surveys, where this method is chiefly recommended, the transport of three stands is of no moment, but in country work it is more difficult, and not so necessary on account of the longer sides obtainable for the polygons.

The Author does not claim any originality either for his signal apparatus or for the idea of alternate exchanges of theodolite and signals, but simply for the extended application of this procedure

in the given form for surveys, and specially for town-surveys. The additional accuracy gained by its use will ensure its speedy adoption.

E. H. C.

Testing-Machines. By Messrs. DENIZEAU and LECHIEN.

(Mémoiral de l'Artillerie de la Marine, 1884, p. 17.)

This Paper concludes a long article on Testing-Machines, an abstract of the first portion of which, dealing with the machines themselves and the mechanical appliances employed with them, has already been given.[1] The present part consists of four chapters, the first three of which treat of the results obtained from such machines, the last being upon the trials by means of powder of the metal of cannons.

The first of these chapters commences with a discussion of the effects of experiments in tension, with special reference to the stress and strain diagrams so obtained. There are two periods, (1) of elasticity; (2) of deformation, the corresponding curves being called respectively the curve of elastic elongation and the curve of total elongation, the latter being supposed to consist of the theoretical elastic elongation, together with a certain permanent extension. The following remarks are made upon the remarkable inflexion on the diagram, which almost invariably occurs just beyond the limit of elasticity:—"In general the curves of total elongation obtained by the engineers of naval construction present a very marked inflexion immediately after the limit of elasticity, of which the director Mr. Mangin has said—'It appears that a new molecular state develops itself under the influence of the effort which passes this limit for a little after the curve resumes a regular formation.'" The curves from the Maillard machine show this inflexion, but it is always less marked than with lever-machines, and the experiments of Ardant indicate that this difference between the curves must be attributed to the very great continuity of action obtained by means of the principle of compressive action upon which the former machine acts. According to Ardant the curves found for unequally annealed wire present, beyond the limit of elasticity, greater or less inflexions, according to the nature of the metal, and more especially according to the manner of operating, which latter exercises a very great influence in the case of ductile metals. If equal loads, to the extent of one-twentieth of the breaking-load, are successively added, the result is a very elongated curve. If, however, very small increments of load at very long intervals are applied, the breaking load is increased, the wire having apparently each time a state of stable

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[1] Minutes of Proceedings Inst. C.E., vol. lxxvii., p. 390.

equilibrium, and maintaining an elasticity which surpasses that found in the previous manner of operating. That is to say, if the wire be left a certain time under the action of the load, its curve shows an inflexion analogous to that of hardened wire. The extent of this inflexion will evidently be in inverse proportion to the total elongation. For this reason machines like that of Maillard would be expected to produce a more regular curve than lever-machines.

In discussing the reduction of area which takes place at the point of rupture on the test-piece, it is stated that with Uchatius bronze the reduction does not, as is usually the case, take place in the middle of the test-piece, but under the heads on enlarged ends, and also that with metal not homogeneous the reduction takes place at several points at once.

The modulus of elasticity, $\left(E = \frac{P}{i}\right)$, where P is the load and i the corresponding extension, is used as a measure of the rigidity (raideur). If ϵ represent the numerical value of the rigidity, then $\epsilon = \frac{E\,A}{L}$ where A is the area and L the length of the specimen. The value of ϵ is measured beyond the limit of elasticity by the cotangent $\left(\frac{d\,P}{d\,i}\right)$ of the angle made by the tangent to the curve at every point. Poncelet has stated that this never becomes zero, but the Authors state that just when the reduction of area at a definite point commences, the rigidity, measured in the foregoing way, is nothing, and becomes negative beyond this until rupture takes place. The various points, limit of cohesion, work of rupture, coefficient of security, effects of shock and repeated oscillations, are then considered, and a few lines ear devoted to compression, bending or torsion. The various conditions which effect the results of trials are next considered; after which follows the discussion of the preparation and form of various kinds of test-pieces, of duration of test, of temperature, and of the appearance of fracture.

Chapter VII. deals with the classification of iron and steel according to their mechanical properties; the methods are given of Karsten, Joëssl, Creusot, Whitworth, Deshayes, and that pursued at the works of Assailly; and, finally, the classification adopted by the French Government is explained. Chapter VIII. treats at length of the conditions upon which cast- and wrought-iron and steel are received for employment by the Marine Artillery service, based chiefly on the instructions issued in 1882, giving details for the trials for the body, tubes, and various parts of ordnance. The form and dimensions of test-pieces for tension, bending and the effect of shocks are given. The exact conditions which specimens must sustain are detailed with great minuteness, not only for the guns themselves, but also for gun-carriages and projectiles.

The last chapter upon the trials by powder gives a brief account of the trials in 1876 by Ruelle of the bursting of small hollow cylinders of cast-metal and alloys. The results were, however, so unsatisfactory that for the Artillery of the French navy trials by means of a testing-machine have been adopted instead, and the results are in entire accordance with the action in practice of the guns, the tubes of which are now only tested with charges of powder with considerably below the bursting charge.

H. S. H. S.

On the Effect of Alternate Heat and Cold on Iron, Steel and Copper. By Edmund Wehrenfennig.

(Organ für die Fortschritte des Eisenbahnwesens vol. xxi., 1884, p. 216.)

It is well known that wrought-iron or steel bars, after being first heated and then suddenly cooled, decrease in length, as well as that in the case of cast-iron the opposite result takes place, viz., an increase in length. Copper in this respect behaves in a similar manner to cast-iron. The Author made a large number of experiments with a view of determining the amount of respective increase or decrease in length for special practical purposes, but his researches being extended beyond what was originally intended, he determined to treat the matter more scientifically.

Experiments with Wrought-Iron.—These experiments were made on round bar-iron ranging from 2·38 inches in diameter to wire 0·04 inch thick. The bars were subjected to different degrees of heat and then suddenly plunged into cold water, or cooled slowly in the air, or in other cases left to cool down under ashes. A series of experiments were made in which, in one case, the iron was heated for five hours, in the second case for thirteen hours, and in the third for eight days during ten hours per day, the furnace cooling down during the night.

Experiments were also made with flat iron and plates.

The following is a summary of the results of these experiments:—

1. A higher temperature imparted to the iron produces greater results than a lower temperature.

For example, in the experiments made with bar-iron 1·04 inch × 1·04 inch in section, the diminution amounted to 0·023 per cent. after the bar had been heated to from 570° to 750° Fahrenheit, and then plunged into water; whilst in another case, where the temperature to which the iron was subjected exceeded this degree, the decrease in length measured 0·087 per cent.

2. Rapid cooling and great range of temperature increase the amount of diminution.

3. The length of time during which the metal is subjected to a high temperature greatly influences the amount of contraction.

4. The form of the metal is also an important factor, as shown by the following result:—

	Inches.		Per cent.	
Round bar-iron	2·36–1·38	diameter, decreased in length by	0·069	Mean of thirteen experiments.
	0·79–0·67	„ „ „	0·065	
	0·31–0·20	„ „ „	0·066	
„ wire	0·12–0·07	„ „ „	– 0·025	

whilst, therefore, the heavier section of bars decrease, almost uniformly the wire increases in length.

In the case of two iron plates, one 0·51 inch, the other 0·20 inch thick, the former decreased in length and breadth but increased in thickness, while the latter increased in all its dimensions.

Experiments with steel.—Ordinary steel under the influence of heat and cold behaves in a similar manner to wrought-iron, but some steels on being subjected to this treatment neither decrease nor increase perceptibly in any of their dimensions.

The following are the results of experiments repeated three times on a bar of steel of 2·28 inches by 1·18 inch section:—

	Per cent.
Diminution of length after first time of heating, and then cooling under exposure to atmosphere	0·001
„ „ second „ „ water	0·125
„ „ third „ „ „	0·107
„ „ fourth „ „ „	0·096
Total diminution	0·329

The Author gives an account of several experiments made with steel tires, and then proceeds to describe the—

Experiments with Copper.—A copper rod 5·871 feet in length with a section measuring 2·18 inches in diameter, together with one iron and two copper wires 0·11 inch thick, and of the same length as the copper rod, were heated to a high temperature and then plunged into water, with the results that—

	Inch.
The copper rod increased in length by	0·138
„ „ wires „ „	0·303
„ iron wire „ „	0·177

Experiments with Cast Iron.—Bars of cast iron—

23·62 inches long,	7·32 inches wide, and	1·65 inches thick,	
20·00 „	7·32 „	1·65 „	
20·04 „	7·32 „	1·65 „	

were heated and then allowed to cool by exposure to the atmosphere or by plunging into water, thereby producing a mean increase of length of 0·051 per cent.

The behaviour of brass under this treatment is similar to that of wrought iron, only more marked.

The rest of the Paper is devoted to exhaustive speculations as to the cause of the respective contraction and expansion of the

different metals, as well as to the explanation of several everyday occurrences to boilers, engines, &c., which are continually coming under the notice of the civil and mechanical engineer.

J. R. B.

Bricks and Tiles of Glass or Grit. By — Hignette.

(Comptes rendus de la Société des Ingénieurs-civils, 1885, p. 54.)

The utilization of the heaps of residue from the operations of the looking-glass manufacture has been successfully effected, on the system of Mr. F. Motte, in the production of white bricks and stones. In polishing mirrors, the surfaces are rubbed with platforms of wood framed in cast-iron, interposing fine sandstone, or white quartzose sand, with the addition of water. The water, as it escapes as mud, carries with it the sand employed in grinding, mixed with glass and cast-iron. The proportion of glass, as impalpable powder, is about 15 per cent. of the weight of the sand; and there is 2 per cent. of iron. The muddy water is delivered into basins where the solid matters are deposited. The deposit is collected, and ultimately becomes enormous heaps. It is very absorbent, and holds at least 30 per cent. of water.

The solid matter is dried to a convenient degree, brayed, kneaded, and put into moulds of the required form, in which it is subjected to a pressure of about 2 tons per square inch. The pieces thus moulded are dried, and burnt in a kiln at a temperature above that of melting glass, about 3,000° Fahrenheit, the glass, by its melting, constituting the cement by which the silica is held together. The soda in excess at this temperature combines with the silica. The iron is reduced, and a perfectly white product is obtained. This new material is light: its density is only 1·50, whilst that of clay bricks is 1·85.

This material, consisting of silica and glass, is usefully employed in chemical manufactures. The bricks are used to line lead chambers. They resist the action of sulphuric acid and hydrochloric acid. They are more or less compressed, according to their destination; and their power of absorption varies from 20 per cent. to 25 per cent. They are unaffected by frost. They have a crushing resistance of from $2\frac{1}{2}$ to $2\frac{3}{4}$ tons per square inch, whether dry or after forty days' immersion in water. The material, in mixture with other substances, makes fine clays, paving-stones, &c. In architecture, it is ornamental. It is homogeneous, and is easily cut. In price, bricks of the new material vary from £2 to £4 per thousand.

D. K. C.

The Kaolin Beds of Chester and Newcastle, U.S.A.

By Graham Spencer.

(Proceedings of the Engineers Club of Philadelphia, February 1885, p. 302.)

The greater proportion of kaolin, or china clay, used in the potteries of the United States is mined in the States of Pennsylvania and Delaware. The quantity shipped in 1884 was nearly 20,000 tons. Kaolin, resulting from the decomposition of a rock composed of felspar and quartz, is found in pockets or beds on clay, in low and occasionally swampy ground. It is bedded against veins of talc, very irregular in pitch, but eventually cutting the clay out. The talc is bedded against partly decomposed mica-schist, and often against iron or manganese.

Kaolin is generally proved by boring, or by sinking small shafts. When the position of a deposit is determined, the overlying soil is removed and the clay uncovered. The clay is toilsome to excavate; the strongest steel-pointed shovels are required for the work. It is removed by means of carts, cars, or derricks, and the bed is drained by pumping. The clay, as extracted, is treated in the washing-machine, in which a horizontal shaft, 3 inches or 4 inches in diameter, carrying knives 12 inches long, at 4 inches of pitch, revolves. A stream of water is turned on, and the clay is charged at the top or hopper entrance. It is divided as it passes through the machine, and the sand or quartz delivered with the clay and water settles in a box or sump, whence it is continually shovelled out. The clay combined with water, to the consistency of cream, runs slowly off into a number of troughs, where impurities settle to the bottom, and whence it is turned into large vats, where it remains until it becomes "quite thick." From these it is pumped into filter-presses, which consist of wooden panels or diaphragms, each of which contains a canvas bag. The water escapes through the interstices of the canvas, and the clay is of such consistency that it can be handled and placed on shelves in open air to dry ready for shipment.

Kaolin is improved by exposure. If piled and allowed to freeze and thaw in winter, it is found to be the tougher for it in the spring. From 30 to 50 per cent. of washed kaolin is obtained from the crude clay. The quartz washed from the clay is pulverised and sold at 50*s.* per ton to the potters, who use it in the body of the ware, and also with felspar as a glaze. The mica or talc makes a good fire-brick.

D. K. C.

Report on the Public Works of the Island of Cuba from 1873 *to* 1882.

Addressed to His Excellency the Colonial Minister of Spain by the Inspector-General of Public Works, LEONARDO DI TEJADA.

(Revista de Obras Publicas, vol. l., parts 9–16, May 15 to Aug. 30, 1884.)

This is a voluminous report, a large portion of which is devoted to a recapitulation of the numerous laws, royal orders and local instructions, which regulate the public works of the Island of Cuba, and explanations are given of the many unfavourable influences which have retarded their progress. Reports on these works ought, according to law, to be addressed every year to the Colonial Minister, but since the year 1854 only four such have been drawn up; the first was published in 1861 and referred to works constructed between the years 1795 and 1858; the second (published in 1866) to the period comprised between 1859 and 1864; the third (still in the press) to the years 1865 to 1873, and the fourth to the period now under examination from 1873 to June 30th, 1882. The war in the island, which began in 1868, and continued (with a short interval during 1878) until 1880, occasioned a scarcity of funds which materially interfered with the construction of public works.

The existing organization of the engineering service in Cuba is founded on a Royal Decree, dated March 27th, 1866, by which it was provided that there should be an inspector-general of public works, a consultative board, local boards, and an inspector in each of the departments, and lastly, district engineers, the whole under the supervision of an administrative director-general. But this decree has been so frequently modified by subsequent Royal Orders, that it is almost impossible to determine what are at the present time the attributes of the several officers; eleven such orders are cited in proof of this statement.

The governor-general of the island now exercises the attributes of director-general, the central consultative board has been removed to Spain, and the civil governors of the provinces have been placed at the head of the provincial engineering departments. All plans, recommendations and reports by the district engineers have to work their way tediously through these several administrative bodies to the ministry of public works in Spain and back again before action can be taken upon them; and the writer cites, as an example of the great loss of time which is occasioned by such formalities, the fact that recommendations, which he himself submitted in May 1880, are still at this moment undecided, and passing through their regular course from office to office. This is in part due to the circumstance that the number of inspectors and engineers now in the island is much below the proper establishment, so that all are overworked, there being at the present time only four chief engineers, one engineer of the first class, and sixteen assistants in the whole island. Although

the sums assigned for public works have always been very limited, not more than 40 per cent. of such sums have been applied; contractors have been left unpaid; workmen's wages have fallen into arrear; on three occasions, in 1875, 1878 and 1882, debts due have been arbitrarily cancelled; and at the present time it is useless to announce works by public competition, since no bidders present themselves.

The writer of the report suggests a variety of ways in which the management of the public works of the island might be improved, and recommends that some of the two thousand prisoners now in confinement should be employed by the government in their construction.

With reference to railways it is stated that, almost without exception, they have been constructed without any state assistance and on concessions granted in perpetuity, but the railway from Santiago de Cuba was assisted by a loan, without interest, of 360,000 dollars (£72,000) of which the greatest part has been refunded. There is no uniformity in the tariffs, and although the central government ordered their complete revision in 1874, it has been impossible to compel the companies to agree upon the mode of effecting this.

The most important line is that called the Central Railway, which will ultimately connect all the provincial capitals and the most important towns with Havana.

The extent of concessions for public lines of railway granted between July 1st, 1873, and June 30th, 1882, has been 130 kilometres (81¼ English miles), of which 33 miles have been completed and 15 are in construction, and during the same period 55 miles of private lines have been conceded. These figures, however, do not include other works which had been commenced previous to July 1st, 1873, and have since been completed, and many lines have been constructed by landed proprietors, without any authorization from the state, for the conveyance of their own produce.

O. C. D. R.

Compressed-Air Foundations for the Coudray and Evry Overfall Weirs. By G. Lavollée.

(Annales des Ponts et Chaussées, 6th series, vol. viii., 1885, p. 272, 2 plates.)

The overfalls of the Coudray and Evry weirs, situated respectively 2½ miles above and below Corbeil, on the Upper Seine, were reconstructed in 1882 and 1883 to increase the depth of water in their respective reaches. The works were similar in dimensions; but, though both were executed by aid of compressed air, the methods resorted to were different; the Coudray weir being constructed with caissons, which could be entirely removed, and the Evry weir, with caissons of which the bottom portion was left in place accord-

ing to the ordinary system. Both overfalls consist of a rubble-masonry foundation, 23 feet wide, supporting an ashlar-masonry apron and sill, upon which the frames of the weir, bearing hooked needles,[1] are placed. The aprons of the new weirs, placed above the old sites, have their surfaces from 7½ feet to 8 feet 10 inches below the new water-levels; they stretch from an abutment, on one bank, to a pier in the river, situated at one side of the navigable pass.

The Coudray overfall, having a total length of 260 feet, and a maximum thickness of apron of 11⅔ feet, was founded in a maximum depth of 20 feet, on a bed consisting for half the length of sand and gravel, intermingled with boulders, and for the other half of rock. The site being therefore very unfavourable for ordinary cofferdams, movable caissons were adopted similar to those used for the foundations of Garrit and Mareuil bridges.[2] The caisson was 65½ feet long, 20 feet high, and 25½ feet wide. A movable horizontal partition or floor, whose supporting guides were attached by bolts or brackets at the sides of the caisson, separated the caisson into two parts, the lower portion forming the working-chamber, with a clear height of 8½ feet. The caisson was provided with three air-locks, one large central one for admitting the larger materials, and two smaller ones, through which the excavations were removed, and the mortar and rubble stone admitted. The weight of the caisson alone was 80 tons, and with the shafts and locks amounted to 118 tons. The foundations were executed in four sections; and the interval between two adjacent lengths, founded by means of the caisson, varied between 4 and 5 feet. The works were commenced in January, 1882; and the caisson was erected in six weeks on staging over the site it was to occupy, and the process of sinking was commenced in June. Full details are given of the sinkage and removal of the caisson in the construction of the four lengths of apron. The length of foundation adjoining the bank was executed first; and it had been intended to proceed in open air, under shelter of the caisson, as soon as the first 4½ feet had been executed in the working-chamber. The permeability, however, of portions of the bed would have exposed this small thickness of masonry to too great a pressure upwards; so all the masonry was built under compressed air, by gradually raising the caisson as the work proceeded. The caisson was weighted at first with 350 tons of pig-iron and 180 tons of sand, which were gradually removed as the caisson was raised and the water pressure diminished; and the caisson was lifted by twenty screws, capable of exerting a power of 300 tons. The first sinkage occupied twenty-four days; the caisson was sunk about 11 feet in the ground, and its extrication occupied eight days. The whole operation, including the construction of the first length of apron and the removal of the caisson, occupied two months. The

[1] Minutes of Proceedings Inst. C.E., vol. lxv., p. 453.
[2] *Ibid.*, vol. lxv., p. 386.

second length was immediately commenced, on August 5th, by sinking the caisson close to the river-pier, which was attended with considerable difficulty, owing to the variable nature of the bed, and as portions of the foundations of the old pier had to be removed for the passage of the caisson. When the limit of $4\frac{1}{2}$ feet of thickness of masonry that could be executed in the working-chamber had been attained, the caisson was raised 2 feet to enable the thickness to be adequately increased to resist the upward pressure through fissures in the rock; and a sill of concrete was formed under the edge of the caisson, on which it could rest whilst the remainder of the work was executed in the open air. The sinkage of the caisson for the third length was commenced at the end of October, and occupied twenty days, being hindered by a flood; and the work was then suspended till February 1883. An attempt was made to build the upper portion of this third length of apron in the open air; but the $4\frac{1}{2}$ feet thickness of masonry cracked under the upward pressure of water, when the pressure of the air was withdrawn, and let in the water. Accordingly, the caisson was lifted gradually, as in the first instance, and the whole of the masonry was built under compressed air. The last length was also constructed in a similar manner.

The overfall of the Evry weir, 221 feet long, founded on a stratum of sand and clay intermingled, at a depth of 23 feet below the water, was constructed by aid of caissons partly left in the work. Two caissons were employed, $106\frac{3}{4}$ and $107\frac{1}{4}$ feet long respectively, 23 feet wide, and $24\frac{1}{3}$ feet high. Four air-locks were provided for the passage of workmen, cartmen, and concrete. The working-chamber had a clear height of only $5\frac{1}{4}$ feet, to reduce to a minimum the portion to be filled in under compressed air. When the caisson had been sunk to the requisite depth, the bottom was levelled, being excavated to within 9 inches of the bottom edge of the caisson round the outer portion, and being left 6 inches higher in the central portion; and the working-chamber was filled with concrete. The air-locks and shafts were then removed, and the masonry was built up within the sides of the caisson above the working-chamber. The sides of the caisson rising above the sill were then unbolted and removed. The intervals between the several sections in each of the weirs were filled up with concrete, after closing the ends with panels, or piles and planks. The total cost of the work at Coudray was £12,000, and at Evry £9,350. The cost per cubic yard amounted to £4 10*s.* 9*d.* at Coudray, and £3 6*s.* 9*d.* at Evry. This large cost was in great measure due to the masonry having being stopped, in these instances, at a depth of $7\frac{1}{2}$ feet below the water-level, instead of being raised above the water, as in the case of piers and quay-walls. Under these latter conditions the cost per cubic yard would have been reduced to £2 15*s.* 9*d.* and £2 8*s.* 6*d.* respectively. The difference in cost of the two methods was due to the longer operations with the movable caisson, the work at Coudray having occupied about

double the time of that at Evry. The work at Coudray, however, was somewhat novel, being performed with larger movable caissons than had been previously used. This method has the advantage of leaving no iron in the structure, of avoiding the difficult operation of completely filling the working-chamber with concrete, and of obviating dislocations in the masonry during sinkage. The weir at Evry cost less than some other weirs on the Upper Seine constructed within cofferdams, showing that under certain conditions the compressed-air system is cheaper than the ordinary methods.

L. V. H.

The New Bridges over the Elbe at Madgeburg.

By A. Sturmhoefel.

(Deutsche Bauzeitung, 1885, p. 37.)

The Elbe at Magdeburg divides into three channels, viz., the Strom Elbe, the Middle or Zoll, and the Old Elbe. The first-mentioned is the navigable channel, its water-level being maintained by weirs, the overflow running into the two secondary channels a short distance above the town, the Zoll Elbe, however, being connected with the main stream near the town.

The old bridge over the Strom Elbe was replaced in 1862 by a lattice girder bridge of three spans, carried on stone piers. The bridges described by the Author were recently erected under his direction to replace the ancient structures over the other arms, viz., the Zoll Bridge and the Long Bridge, the latter constructed in 1422. In 1872 it was decided to rebuild these bridges, but the works of the Zoll Bridge were not commenced till October, 1879, and of the Long Bridge till 1880, both being opened for traffic in June, 1882. The Zoll Bridge comprises three arched openings, the centre one being elliptical, of 57 feet 9 inches span, and the two side ones (semicircular) each of 32 feet 9 inches span, with piers 9 feet 10 inches in breadth; the roadway is 26 feet 3 inches broad, and the footways 9 feet 6 inches, or a total width between parapets of 45 feet 3 inches. The Long Bridge is principally for flood-water, and comprises eleven openings, each of 48 feet 6 inches span; the arches of segmental form, with radii of 49 feet 3 inches, the bridge being divided into three groups of three, five, and three arches by two piers of extra breadth, viz., 14 feet 9 inches, the other piers being 7 feet 10 inches broad. The clear breadth between the parapets is 39 feet 4 inches, that of the roadway 23 feet, and of each footway 8 feet 2 inches. The foundations in all cases are carried down to the rock, the average of which at the Zoll Bridge was 13 feet 2 inches, and at the Long Bridge 6 feet 7 inches below zero (flood-level = 19 feet). In some instances the masonry was laid immediately on the rock, but as a rule a bed of concrete 3 feet

3 inches in thickness was spread before commencing the piers. In both bridges powder-chambers are left in each pier for strategic purposes in the event of war. The material principally used is sandstone, but the balustrading is of granite. The water- and gas-pipes and the telegraph-wires are carried in a subway beneath the footways. The Zoll Bridge is ornamented with four groups of statuary, and the Long Bridge with obelisks on the intermediate piers, and figures of lions at the abutment terminals. Plans and elevations, together with a general plan, accompany the Paper. The cost was as follows:—

	£.	s.	d.	
The Zoll bridge	13,654	18	0	
„ Long „	30,270	16	0	
„ approaches	3,800	0	0	
Statuary and obelisks	1,386	13	0	
				Marks.
	£49,112	7	0	(1,270,000)

The outlay was less than the original estimate, which amounted to £63,500.

D. G.

Bridge over the Dnieper at Jekaterinoslaw.

By Nicolas de Bélélubsky.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 1884, p. 333.)

On May 18, 1884, the new Jekaterinen railway was opened. It is about 294½ miles in length, and consists of two sections; the eastern between the towns of Jeasinowataja on the Donetz line, and Sinelnikowo on the Losowo-Sebastopol, and the western between Jekaterniosław on the Dnieper and Dolinskaja on the Charkow-Nicolai line.

The new line has two noteworthy bridges: that over the gorge of the River Inguletz, and that over the Dnieper at Jekaterinoslaw. The bridge over the Inguletz is 1051 feet long, the height from low water to rail-level being 161 feet, and from the bottom of caissons of the river piers, 223 feet 9 inches. The roadway is carried on the top of the girders of the five openings, four of which are spanned by braced girders with parallel flanges, and one by inverted parabolic braced girders.

The Jekaterinoslaw bridge takes the third place amongst European bridges for length (not including the incompleted bridges over the Forth and Tay). The bridge is in two stages, with the railway carried on the lower members of the girders, and a carriage and footway on the top. The total length is 4,094 feet 7 inches between the abutments, and consists of 15 openings of 273 feet 3 inches each (centre to centre of piers). The underside of the girders is about 43 feet above low water, and 15 feet above

the highest flood (1845). The river is navigable only up to Jekaterinoslaw. The iron superstructure consists in each span of two framed wrought-iron girders with parallel flanges 19 feet apart, 270 feet 8 inches long, 32 feet deep, and divided longitudinally into twenty-three bays of 11 feet 6 inches each by the braces. Between these are two systems of cross-girders and longitudinal bearers, the lower carrying the railway (single line), and the upper the planked carriageway, the footways being bracketed out. The carriageway and footways have a combined width of about 32 feet 9 inches, and are about 29 feet 6 inches above rail-level. The bottom of the river consists partly of granite covered with sand, partly of sandy clay and mud overlying white compact clay. On the right bank granite occurs in considerable quantity. The right abutment, and the first river-pier were founded directly on the rock by means of a bell caisson, a method here used for the first time in Russia. This caisson, which was in plan of the same shape as the pier, was sunk to the rock, and men working in it under pneumatic pressure levelled the rock, and laid the masonry foundations; the caisson being gradually raised as the work proceeded, until the work was carried up to low-water level. The bell was subsequently used as the permanent caisson for pier No. 4. All the other piers and the left abutment are founded upon caissons resting part on rock, and part on the white clay at an average depth for all piers of 46 feet below low water. The deepest being pier No. 14, next to the abutment, which is founded at a level of 59 feet below low water (131 feet 3 inches below the carriageway).

All the stonework of the bridge is granite, quarried on the spot. The piers are 44 feet 9 inches long, and 15 feet 4 inches wide, rounded at the ends. To bring the carriage-road to the main bridge at each end, there is a subsidiary viaduct 233 feet long, consisting of three spans of inverted parabolic girders at an angle of 21° with the railway.

The total length of the bridge, including these approaches, is 4557 feet, or only 315 feet less than that of the great bridge over the Volga.

There were used in the bridge about

33,022 cubic yards stone;
3,280 tons Portland cement;
10,000 „ iron (exclusive of caissons).

The iron for the bridge was rolled from old rails at the Russian works in Brjansk. A great number of tests gave the average tensile strength at 21·6 tons per square inch, and an extension of 12 per cent. The Portland-cement mortar was mixed one of cement to four of sand above water, and three of sand below water. The building of the bridge occupied three years (1881–4), and the total cost was about £495,000.

The adjoined Table shows details of a number of large European bridges for comparison.

In Order of Length.	Name of Bridge.	Length. Feet.	Number of Openings.	Number of Lines of Rails.	System of Girders. Position of Roadway.	Kind of Piers.	Foundation.	Date of opening.	Cost in £. of whole Bridge.	Cost in £. per Lineal Yard.
1	Alexandrowsky Bridge over the Volga, Orenburg Railway . .	4,871	13	1	Parallel, braced, road below	Stone . .	Piers on caissons; 1 abutment on rock, other on piles .	1880	759,236	461
2	Moerdyck Bridge over the Hollandsch-Diep, Breda - Rotterdam Railway	4,854	14	1	Half parabolic; road below	Stone . .	3 piers on caissons, the rest on piling	1872	553,777	342
3	Dnieper Bridge, Jekaterinoslaw, Jekatorinen Railway (Russia) . .	4,095	15	Road above; railway (1 line) below. . .	Parallel, braced. .	Stone . .	13 piers and 1 abutment on caissons, 1 pier and 1 abutment on rock .	1884	498,483[1]	365
4	Dnieper Bridge at Kiew	3,519	12	1	Lattice girders, road below	Stone . .	Piers on caissons and abutments .	1870	383,452[1]	327
5	Dnieper Bridge, Krementschuz . . .	3,199	11	Single line, with street at same level . . .	Lattice girders, road below	Stone . .	All piers on caissons, abutments on caisson, concrete and piling.	1872	467,173[1]	438
6	Waal Bridge, Utrecht-Boxtel Railway (Holland)	3,016	11	1	Half parabola girders, road below .	Stone, for two lines	All piers on concrete	1868	240,380	239
7	Kuilenberg Bridge over the Leck, Utrecht-Boxtel Railway . .	2,315	9	2	One opening, half parabola girders, with road below; remainder parallel, braced girders, road above .	Stone . .	All piers on concrete	1868	220,953	286
8	Menai Bridge . . .	1,831	4	2	Tubular, road below	Stone . .	All piers and abutments on rock .	1848	603,471	989
9	Weichsel Bridge, Warschau (Russia) . .	1,666	9	Road below; railway above	Lattice girders . .	Stone . .	All piers on caissons	1876	139,399[1]	251
10	Msta Bridge, Nicolai Railway (Russia) .	1,052	4	2	Lattice girders, road	Stone; rails to low water (148 feet)	All piers on caissons	1882	202,007[1]	576

[1] Price given in credit roubles; others in metallic roubles. 1 metallic rouble is taken at 3*s.* 2½*d.* + ; 1 cred. rouble is taken at 2*s.* 6¾*d.* +

At the testing each span in turn of the railway was loaded with six eight-wheeled locomotives, and the carriage-way with rails. The deflection was $1\frac{1}{4}$ inch ($\frac{1}{2800}$ of the span). The design of the bridge is by Professor N. Bélélubsky, of St. Petersburg; M. W. Beresin was the resident engineer.

W. B. W.

Re-erection of the Tardes Viaduct. By C. Talansier.

(Le Génie Civil, Jan. 24, 1885, p. 198.)

A general description of this viaduct, and of its destruction by a gale of wind while in the course of erection, having been given in a previous volume,[1] the present article will be confined to an account of the reconstruction and rolling out of the ironwork.

The accident took place on the 26th of January, 1884. All the new ironwork was delivered at the site by the 15th of July. The rolling out was commenced on the 17th of September, and the girders were finished and in position on the 10th of December.

It was decided to again roll the girder out from one end, but the method of doing this was modified so as to avoid another catastrophe. The reactions of the piers at one period of the operation amounted to 700 tons, and as it was decided not to allow a greater weight than 30 tons upon each roller, twelve rollers were required upon each pier. Each roller was a wheel 20 inches in diameter working upon an axis. Upon the top of each pier, and resting upon steel pivots, were placed two wrought-iron girders 20 feet 6 inches long, connected by cross-girders. Half way between the centre and one end of these girders rested another pivot supporting the centre of a smaller pair of girders, at the ends of which were placed four frames, each frame carrying two rollers. At the further extremity of the large pair of girders two similar frames were placed. By means of this arrangement the bridge-girders bore equally upon each of the twelve rollers throughout the process of rolling out, and the whole weight was transmitted to the centre of the pier. The transverse distance between the rollers was such as to bring them between horizontal rows of rivet heads in the bridge-girders, which thus served as guides. Strong oak frames fixed upon the piers prevented any lateral movement of the girders from wind-pressure. Upon these frames were placed hydraulic rams, which were provided in case any unequal settlement should take place during the process, and were afterwards employed to release the rollers and hold up the girders while the permanent supports were being placed in position. In order to facilitate the operations, a staging was erected in the right-hand span, at a distance of 90 feet from the abutment.

The approach of winter rendered it necessary that the ironwork

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[1] Minutes of Proceedings Inst. C.E., vol. lxxviii., p. 466.

should be moved out clear of the abutment with the utmost rapidity, so that the masonry might be completed before the frost set in. On account of the curvature of the line it was not possible to erect a greater length than 220 feet in the cutting at the end of the bridge. When this length had been put together the rolling out commenced. The manner in which the erection and rolling out were carried on is fully described in the Paper, and illustrated by a series of diagrams showing the various steps of the process.

W. H. T.

The Lift-Bridge over the Arm of the Danube at the Alt-Ofen (Buda) Dockyard.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 1885, p. 14.)

The dockyard island of Alt ofen (Buda) is joined to the town by a newly constructed iron lift bridge from the designs of Herr Peter Remmel, of the Danube Steamship Company. The bridge is 184 feet long, and consists of three openings; two side-openings of 49 feet 3 inches, the girders of which are fixed, and a centre opening of 68 feet 10 inches, constructed to lift. The girders are ordinary braced girders, 7 feet 1 inch deep, with parallel flanges, and the roadway (which is 17 feet wide) is carried by braced cross-girders, 1 foot 11½ inches deep, and 6 feet 7 inches apart, and longitudinal bearers 1 foot 11½ inches apart, supporting planking upon which wood pavement is set.

Upon the two piers there are braced wrought-iron superstructures, 28 feet 5 inches high, above level of girder-beds, and each consisting of two towers 4 feet 5 inches square, connected near the top for stiffness. These serve to guide the bridge while it is lifted, and within them travel the counterweights which effect the lifting. The ends of the two main girders of the lift-bridge are connected with the counterweights by double chains passing over pulleys at the top of the towers. The counterweights exactly balance the weight of the bridge (about 44 tons); in raising and lowering, therefore, there is only the friction to be overcome. It was originally intended to do this by means of a rack and pinion, but ultimately chains were employed. For this purpose a winch is fixed at the centre of each girder, by means of which two chain-pulleys upon a common axis are put in motion. Over each of these pulleys run a chain, one end of which is fixed to the base of one of the pier-towers, and the other end having been passed round a pulley fixed to the end of the girder is made fast to the top of the pier-tower. Thus, by working the two winches, for which two men are required, the bridge is raised 13 feet in about 7 minutes, giving a total headway of 42 feet 8 inches above low water. The cost of the bridge was £5648. The paper is illustrated.

W. B. W.

Fall of a Bridge over the Werdenberg Canal at Saler-Buchs.

(Schweizerische Bauzeitung, vol. iv., 1884, pp. 22–23, 136–138, 145, 146.)

This road-bridge (No. 13) is the most important of the nineteen which cross the new canal, constructed to give an outlet into the Rhine below Rutli for the flood-waters of the St. Galle valley.[1]

It crosses the canal at an angle of 45° with a span of 114 feet 10 inches, a width of roadway of 9 feet 8 inches, and a headway above the canal of 17 feet. The specification required the bridge to sustain a distributed load of 61·5 lbs. per square foot, or a wagon loaded with 7·8 tons without permanent set and with a deflection of not more than $\frac{1}{2,000}$ of the span. The testing took place on November 13th, 1884. Fifteen wagons with about 51 tons weight were already upon the bridge when, without any observed bending of its parts, it collapsed. The observed deflection at the time was 0·39 inch or 0·3 inch less than the amount allowed. The main girders were of a simple triangulated form, with parallel booms, the roadway being carried on cross-girders, supported alternately from the points of intersection of the braces with the top and bottom booms respectively. The braces made angles of 60° with the booms and with one another.

When the roadway was laid down a bending of the third compression-brace (consisting of two channel-irons 5·1 inches by 1·75 inch) was observed, and the moment of inertia of the cross-section of the brace was increased by separating the channel-irons by a distance of about $\frac{3}{4}$ inch.

It was necessary after the roadway had been formed to change one of the girder bed-stones, and for this purpose the bridge was lifted about 3 inches from below the second cross-girder, and its elasticity was thus much tried.

A slight flaw, $4\frac{3}{4}$ inches long, was, after the accident, found in one of the plates of the bottom boom, but even if this existed before the fall (and it was first noticed four days after the fall), it only weakened the cross-section by $\frac{1}{6}$, and will not account for the failure, the cause of which is to be sought in errors of construction involving the too great straining of particular parts.

The roadway held together well, and the cause of the collapse of the bridge need therefore not be looked for there.

The weight of the structure was as follows:—

		Lbs.
Ironwork	per lineal foot	873·6
Roadway	„	1,478·4
Load, 61·5 lbs. per square foot .	„	1,209·6
		3,561·6

or 1780·8 lbs. per foot-run on each main girder. The metal in the bottom boom, and in the tension braces was not strained more

[1] Minutes of Proceedings Inst. C.E., vol. lvii., p. 354.

than 4·4 tons per square inch; even allowing for the flaw mentioned above in one of the plates of the bottom boom it was only strained to 5·2 tons per square inch. The top boom was of the Gerber section; four angle-irons back to back, an arrangement in which the material of the cross-section is for the most part concentrated near its centre of gravity, giving a small moment of inertia. The height of the cross-section is only $7\frac{7}{8}$ inches, which is but $\frac{1}{30}$ of the distance between the points of intersection of the braces with the boom. This proportion demands that the top boom shall be calculated not only for its resistance to an equally distributed pressure but also for its resistance to buckling. This latter point had been neglected by the designer of the bridge. Two of the braces were similarly weak, and there is no room for doubt that this was the cause of the collapse of the structure; but whether the braces or the boom first buckled there is nothing to show.

W. B. W.

The Blaauw-Krantz Railway Viaduct, Cape-Colony.[1]
By Max am Ende.

(Centralblatt der Bauverwaltung, 1884, p. 476.)

This bridge, over the Blaauw Krantz Ravine on the Grahamstown and Port Alfred Railway was opened for traffic on September 10th, 1884. The gauge of the railway is 3 feet 6 inches, and the moving load somewhat more than 1 ton per lineal foot. The length of the bridge is 480 feet, divided into a central arch 230 feet span and two double cantilevers, altogether five spans. The height of the central arch is about 100 feet.

The features of the site required a structure which could be erected without scaffolding, and which at the same time had a large opening in the middle; the high freights for ironwork from England to the Cape made desirable a structure which was economical, more as to quantity, than as to workmanship; in fact, the cost per ton manufactured was higher than that for ordinary girderwork. The erection of the lower parts of the arch was accomplished by using the cantilever girders as cranes for suspending them, and the erection of the remaining parts by the projecting method. The arch structure is comparable, rather to the spandril of an arch than to the arch itself, its top line being the horizontal platform, and the outline at each end being an almost vertical straight line. The thickness of the structure therefore varies considerably; it is 8 feet at the base, 3 feet about 1·6 feet above the base, 26 feet at the haunches, and 9 feet at the crown. The width, crossways, at the base is very great, viz., 1 in 16 of the height, and the inclination of the two arches against the

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[1] An illustrated account of this bridge will be found in the "Engineer" April 16, 1885.—Sec. Inst. C.E.

vertical plane is 1 in 4. There are no cross-ties at the base, and the structure therefore acts as an arch also transversally. The triangulation of the spandril is almost throughout double; thus the various bars have their unsupported length reduced, but the system is thereby made statically undetermined in a high degree, for, counting the bars which should be removed to make it statically determined, it is found that their number is at least fifteen, and this implies fifteen unknown quantities in the calculation of strains. The Author has reduced these to nine by treating the lower part of the arch as if it were solid and might be divided into layers, but he treats the upper part accurately. For convenience of calculation the arch is cut in two halves at the crown; each half is treated separately at first with its nine unknown quantities; these are, the three forces which must always be introduced in a cut, which goes through more than one bar, the three elastic movements in the direction of the forces, and the three supernumerary bars. Six of these quantities are equal in both halves, and three have at least certain equal factors attached to them. The equations can therefore be treated in groups, and partially solved and simplified before the two halves are joined together in the calculation. For the formation of the equation the Author refers to Schäffer and Sonne, Brückenbau II., p. 495, and to his article in Engineering 1883, II., p. 509. The calculation of the strains from change of temperature and from wind-pressure is then referred to, and it is stated that, excluding wind-pressure, they do not exceed 3¼ tons per square inch, and including it, 4·8 tons. In order to avoid the uncertainty of the strains which might be caused during the erection, three temporary hinges were introduced into the arch-structure, one at each springing and one at the crown. The total weight of iron in the bridge, including the plates of the iron platform, is stated to be 287 tons.

M. A. E.

The Creeping of Rails on the St. Louis Bridge.

By T. B. Johnson.

(Journal of the Association of Engineering Societies, Nov. 1884, p. 1.)

The rails forming the double line of railway over the St. Louis bridge move in the direction of the traffic at the rate of more than a foot a day. This creeping occurs only on the bridge proper (1,600 feet in length and rising 5 feet from each abutment to the centre) and on the eastern approach (2,500 feet long, gradient 1 in 66, and consisting of short girders on iron columns). Various methods have been tried to keep the rails in place but without success, and the practice is now to leave the rails to creep, cutting out and filling in as may be required at the butments and at the foot of the east approach. This has to be done many times a day at each place.

In the twelve months ending August 1884 the rails of the north line travelled 400 and 401 feet respectively up the approach, and 268 and 260 feet respectively over the bridge, while the rails of the south line travelled 414 and 415 feet respectively down the approach, and 240 and 239 feet respectively over the bridge. The ratio of westward to eastward movement on the bridge is 1·099, and this is exactly the ratio of the westward to eastward tonnage. On the approach this proportion does not hold, the result being affected by the heavy gradient.

An analogous phenomenon is the creeping of bridges on their supports. If a bridge have its two ends similarly mounted, when a train comes upon it from the right this end is at once pinned fast by the weight of the train. The deflection caused by the train lengthens the bottom chord and shortens the top chord of the truss, so that if it is supported at the bottom chord, the left end moves to the left, and if at the top chord the left end moves to the right. As the train passes off at the left end, this end of the truss is pinned fast while it recovers its shape, and consequently if the truss is supported at the bottom chord it will have moved bodily to the left, and if at the top chord to the right.

The Author considers the various explanations already offered to account for the creeping of the rails, showing them to be either insufficient or unsatisfactory. His own explanation, the result of accurate observation, and supported by interesting experiments described in the Paper, is that there is a wave-motion of the rail, independent of its supports, such a wave occurring under each car and moving with it, giving a slight forward motion to the rail every time a given section is brought down upon the support. The total movement for one train will thus vary with the number and weight of the cars. On the bridge the rails (flat-bottomed) rest on pillow-blocks of gum-wood 5¼ inches thick, held in position between longitudinal channel-irons. These blocks are 17 inches long and spaced 19 inches apart end to end. The wave-motion of the rail is due to the elasticity of these supports. The rail is held fast on the supports by the load, on its extended side. This causes it to measure its length across the bridge on its extended side, or it may be said to roll itself across the bridge on its extended side.

If, instead of being supported at the bottom flange, the rail were supported at a point above the neutral axis, there would be a tendency for it to creep backwards, that is, against the direction of the traffic, owing to the compression of the upper side. There would, however, also be a tendency for it to move forward, as the neutral axis when thrown into waves is longer than when at rest. Again if the rail were supported from the upper surface the creeping would be backward. There is, therefore, somewhere between the neutral axis and the upper surface of the rail, a line along which, if the rail were supported, there would be no tendency to creep either forward or backward.

W. B. W.

The Berlin Metropolitan Railway.

(Zeitschrift für Bauwesen, vol. xxxiv., 1884, pp. 1, 113, 225.)

The railway was constructed with a view of connecting the main terminal stations of Berlin, all of which are situated at a considerable distance from the centre of the city, and with the exception of the Anhalt and Potsdam stations, lie outside the closely-inhabited quarters. Another object of the line was to afford communication between different parts of the city and the suburbs, which are of considerable extent. The pre-existing circular railway was very circuitous, and was only employed for goods traffic.

The project for a line passing directly through the city from east to west, and forming junctions with the principal termini, was first started in 1872, but on account of the numerous objections raised by the different authorities to the various schemes proposed, the actual construction was delayed until 1879. The capital necessary for the construction of the line was to have been subscribed jointly by the Government and the railway companies thereby affected in the following proportion:—

1. Government	$\frac{7}{16}$
2. Berlin-Potsdam and Madgeburg Railway . .	$\frac{1}{8}$
3. Madgeburg and Halberstadt ,, . .	$\frac{1}{8}$
4. Berlin and Hamburg ,, . .	$\frac{1}{16}$
5. German Railway-construction Company . .	$\frac{1}{4}$

On the third instalment of 10 per cent. of the share-capital becoming due, the German Railway Construction Company found themselves unable to raise the required amount, in consequence of which their shares were confiscated. At this period more detailed estimates showed that the previous estimate was insufficient; the company was hereupon liquidated, and the Government determined to carry out the work itself—the three railway companies which had already paid in their instalments subscribing 40 per cent. of their liability, or between them about £300,000, for the privilege of obtaining running-powers over the line.

In determining the course of the line, little or no attention had to be paid to levels, the chief point to be observed being to avoid valuable property and the neighbourhood of heavy street traffic. A very large number of schemes were prepared before one could be finally adopted, against which the opposition raised by the different authorities was not insurmountable.

The length of the line, including the two terminal stations, is 12,145 metres (7 miles 43·75 chains); about 4,920 metres (3 miles 4·5 chains) of the line consists of curves; 2,270 metres (1 mile 33 chains) is on gradient, and 1,320 metres (65·6 chains) on gradient as well as on curve. The radii of the curves vary from 280 to 500 metres (14 to 25 chains), and the gradients range from 1 in 125 to 1 in 500. Roads were only allowed to be lowered in a very few cases. The difference in level between the commence-

ment and termination of the line amounts to but 0·70 metre (2·3 feet), and the greatest difference between the level of any two points of the line to 3·6 metres (11·8 feet).

The line is an elevated one throughout (rail-level about 18 feet above ground); through the town it is carried on viaduct, the arches of which are let as shops and stores; outside the town embankment, and in some cases embankment with retaining-walls take the place of the viaduct.

The line consists of four tracks throughout; the two northern of which are used for the city and the circular railway, the other two being reserved for the suburban and main-line traffic. It was at first proposed to use the outer lines for the town traffic, and make the inner lines the main-lines, but this idea was eventually abandoned in favour of the present arrangement.[1] The distance between the central lines of way from centre to centre is, as a rule, 4 metres (13 feet), and of the outer lines from the central ones 3·5 metres (11·5 feet).[1] In the stations these distances are in all cases increased to 4·5 metres (14·75 feet).

The 7½ miles of railway possesses four stations, including termini, and five stopping places; and consists of 7,964 metres (4 miles 76 chains) of brick viaduct, including stations and stone bridges; 1,823 metres (1 mile 10 chains) of viaduct with iron superstructure, including iron bridges; 675 metres (33·5 chains) of embankment, supported by retaining-walls, and 1,683 metres (1 mile) of ordinary embankment. The viaducts are, with slight variations, constructed of one pattern, segments of circles being in all cases adopted as the form of arch.

Of the £1,715,000 of the estimate for construction, £620,000 was required for building the viaducts, and it was found that the utmost economy would have to be exercised to make this sum suffice; on this account extensive calculations were made to discover the cheapest types, of which five were selected in which the span of the arch ranged from 6 to 15 metres (19·7 to 49·2 feet), so as in all cases to suit the different local requirements.

The chief dimensions for the different spans are given in the following Table:—

——	Span of Arch in Feet.					Remarks.
	19·7	26·2	32·8	39·4	49·2	
Rise of arch	1/4	1/6	1/4·5	1/4	1/3·5	
Thickness of arch at crown.	1·25	1·67	1·67	2·10	2·53	The ideal ground - line is assumed at 17·4 feet below rail-level.
" " springing	1·25	1·67	1·67	2·10	2·53	
Thickness of pier . . .	2·60	3·28	3·28	3·94	5·25	
" " at ideal ground-line	2·60	3·28	3·94	3·94	..	

[1] "Deutsche Bauzeitung," 1878, pp. 118, 138, 155.

The strains in the viaducts for the formation of the above Table were calculated graphically, and were based on the following assumptions:—Weight of brickwork, 2,700 lbs. per cubic yard; weight of backing, 2,700 lbs. per cubic yard; depth of backing, 2·6 feet; live load reduced to dead load, 2·6 feet; the limit of compression of brickwork in arch, 128 lbs. per square inch; of brickwork in piers, 107 lbs. per square inch; and that of foundations, 64 lbs. per square inch.

In the calculations of special structures, the above values were slightly departed from, especially as regards weight of brickwork, which as a rule was taken at 3,000 lbs. per cubic yard.

In order to obtain reliable data for the design of the piers as regards distance apart and width of foundations, a series of borings at intervals of a chain was taken as soon as the line had been set out. The foundations as a rule were good, sharp sand being in most cases met with at a short distance below the surface; in a few isolated cases, however, a tolerably good foundation could only be obtained by excavating to a considerable depth.

The different kinds of foundations in the viaduct are—

	Lineal yards.
Brickwork	5,020
„ with timbering	848
Concrete „ „	1,536
Caissons	695
Piles	614

Every fourth to sixth pier is constructed sufficiently massive to withstand the one-sided thrust of an unloaded arch. Those piers enclosing spaces to serve as stores and shops are provided with one or two openings connecting the different spans; these vary greatly; in the first viaducts built they are comparatively low and narrow, but in the later ones they are wider, and extend in many cases above the springing, and on that portion of the viaduct crossing the Königsgraben they are carried up as high as the crown of the arch. The arches are covered with a course of perforated bricks, in order to keep from the arch any moisture which is liable to force its way through the backing. The course of perforated bricks is covered with sheets of asphalt felt about half-an-inch in thickness. In the small viaducts the spandrils are filled with concrete, whilst in those of larger span they are constructed hollow with from one to five divisions, according to their size. The drainage of the viaducts is effected at the piers, but the method varies considerably in different cases.

As a substitute for the extra width which it was originally intended to give the viaduct, but which had to be abandoned on account of the cost (£60,000), a trough 2·3 feet wide and 2·7 feet deep, acting as a refuge for platelayers and others engaged on the line, was constructed along the centre line of the viaduct throughout its entire length. The efficiency of this trough is very doubtful, and the Author greatly regrets that the width of the six-foot way was not increased in spite of the cost.

During the construction of the viaduct a number of experiments was made to discover the maximum batter which could be given to the sides of the foundations, as well as the amount of pressure the ground, consisting of sharp sand, was capable of bearing. The experiments were conducted in the following manner:—

A series of fifteen trial piers, built of stocks set in hydraulic mortar (two of lime to five of sand) were erected adjacent to the openings in the piers of a length of completed viaduct; these piers were square in plan, 20 inches wide, with foundations increasing to 40 inches in a direction at right angles to the centre line of the viaduct. The foundations were built to five different batters, viz., 1 in 1·15, 1 in 1·43, 1 in 1·73, 1 in 2·12, and 1 in 2·6. The pressure applied to the trial-piers was central, and equally distributed over the plan of the pier and foundation. For this purpose a wrought-iron girder acting as a lever, one end being attached to the opening in the pier which acted as the fulcrum, was laid across the top of the trial pier, and the longer arm weighted with rails; below the weighted end a hydraulic-jack was placed, so as to allow of each fresh addition to the weight acting gradually. An index attached to the pier registered the amount of settlement in the foundations on a graduated staff driven into the ground a short distance from the pier to be tested. The mortar in the brickwork was allowed four months to set before the experiments were made. The results of the tests are given in the following Table:—

Number of Experiment.	Batter of Foundation.	Uniformly Distributed Pressure in lbs. per Square Inch under which the Brickwork remained perfect.	Settlement of Foundations, in Inches.	Uniformly Distributed Pressure in lbs. per Square Inch under which the Brickwork skewed.
1	1 in 1·15	31	0·027	43
2	„	30	0·015	41
3	„	55	0·077	53
4	1 in 1·43	44	0·027	67
5	„	53	0·062	75
6	„	41	0·039	64
7	1 in 1·73	..	..	..
8	„	53	0·058	77
9	„	41	0·086	58
10	1 in 2·12	..	..	..
11	„	43	0·013	54
12	„	53	0·097	64
13	1 in 2·6	75	0·086	88
14	„	77	0·086	88
15	„	75	0·164	87

There are six bridges on the line over streams, two of stone and the others of iron on stone piers and abutments. One of the

stone bridges is over the Spree, which the line at this point crosses on a curve of 15 chains. The bridge consists of two spans, one of 16·65 metres (54·6 feet), the other of 18·07 metres (59·3 feet), the difference in span being necessitated by the different angle of crossing of the arches, whose radii it was desired to keep equal. The form of the arches is that of a false ellipse struck from five centres, with a radius at the crown of 8·6 metres (28·2 feet), thus enabling ashlar to be dispensed with in their construction. On account of the curve adopted for the arches, and the amount of skew in the bridge, it was deemed advisable to turn the arches in eleven rings, built on the square and tied together by wrought-iron anchors, provided with hinged joints at their centres. Detail drawings and descriptions of considerable length are given in the paper regarding the design, construction, and erection of the other bridges.

J. R. B.

A Railway Train Overturned by Wind.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 13 Dec. 1884, p. 336.)

A train consisting of nine vehicles left Vienna at 6.30 A.M. on December 10, 1884, by the Vienna and Auspang line. Near the Biedermannsdorf Station the last four vehicles were blown off the line, and thrown down an embankment 5 yards high; as the coupling gave way the rest of the train remained upon the metals. Three of the vehicles blown off were passenger carriages, and the fourth a goods van; the former weighing about 8·3 tons each, and the latter about 5·9 tons. The surface exposed to the wind was 161 square feet in the case of the passenger carriages, and 178 square feet in the case of the van. The leverage of the wind pressure may be taken at 6 feet 7 inches, which gives 43·2 lbs. per square foot for the passenger carriage, and 27·9 lbs. per square foot for the goods van, as the wind-pressure necessary for overturning.

W. B. W.

The Life of Steel Rails. By G. Lanino.

(Giornale del Genio Civile, 1884, p. 417.)

The study of the railway conventions having drawn the attention of the Italian Government, and of the concessionaire companies, to this subject, the Author takes the opportunity of putting on record what is known about it in Italy.

The wear of a rail may be measured either by reduction in height or in weight, the former is preferable. Experiments made by Dudley in America point to the conclusion that the loss of weight from the same amount of traffic when the rail is worn is

nearly double that from the same traffic on a new rail; the loss of height is however nearly equal in new and old rails.

The wearing action is proportional to $T\left\{6+2\left(\frac{V}{30}\right)^2+i\right\}$, in which T represents the tonnage, $2\left(\frac{V}{30}\right)^2$ the resistance of the air, and i the gradient per 1000. If h = the wear of the rail, then

$$h = C\,T\left[6+2\left(\frac{V}{30}\right)^2+i\right] \text{ on levels and rising gradients;}$$

$$h = C\,T\left[6+2\left(\frac{V}{30}\right)^2-i\right] \text{ on gradients falling not more than } a \text{ per 1,000;}$$

$$h = C\,T\left[6+2\left(\frac{V}{30}\right)^2+(i-a)\right] \text{ on gradients falling more than } a \text{ per 1,000.}$$

Curves, tunnels, and stopping-places largely increase the wear. The Author considers that $2\left(\frac{V}{30}\right)^2 = 3$, and $a = 6$. Hence the three formulas become $h = C\,T\ (9+i)$, $h = C\,T\ (9-i)$, and $h = C\,T\,(3+i)$. On working these out for gradients varying from 0 to 24 per 1000, and taking C as the coefficient per unit of tonnage for single lines on a level, $h = C\,T\,[1+0{\cdot}111\,(1-6)]$. On the Paris and Bondy line, with maximum gradients of 4 per 1,000, traffic amounting to 16,000,000 tons caused a wear of 1 millimetre on those parts of the line on which the trains ran freely. The German Railway Union states that the traffic for 1 millimetre of wear varies from 10,000,000 to 20,000,000 tons. The South-Austrian gives 10,000,000, and Paris-Lyons-Mediterranean line 28,000,000 tons per millimetre. The Author takes 15,000,000 tons as a fair average for 1 millimetre of wear on lines with easy curves and gradients, without tunnels or stopping-places, and gives for the wear in millimetres

$$h = \frac{T}{15{,}000{,}000}\left\{1+0{\cdot}111\,(i-6)\right\}.$$

A Table follows showing the result of experiments on several Italian lines from which these results are obtained :—

Position of Experiments.	Gradient per 1,000.	Wear per 15,000,000 Tons in Millimetres.		Difference between the Actual and the Calculated Wear in Millimetres.
		Actual.	Calculated.	
1. In the open	27	2·72	2·66	0·06
2. Tunnel of Ariano . .	15	3·55	2·00	1·55
3. Tunnels of Starza and Cristina	17	3·29	2·22	1·07
4. Tunnel of S. Domenico .	22	6·40	2·78	3·62

In the first series of experiments the actual wear agrees almost exactly with the calculated, thus confirming the formula. The second and third series show the influence of tunnels. The S. Domenico tunnel is at the bottom of a gradient of 25 per 1,000, the excess is 3·62, and if from this 1·07 is deducted as the wear due to the tunnel, there remains 2·55 as the effect of the brakes.

The Author considers that when the mean wear of the rails on a line reaches 10 millimetres the rails should be renewed; hence if the traffic upon a railway is known the life of the rails can be calculated.

W. H. T.

Lartigues' Monorail System of Way.

(Compte Rendu de la Société des Ingénieurs-civils, 1884, p. 20.)

The Lartigue system, which has already been noticed,[1] was at work at the Rouen Exhibition of 1884, on a small plot of ground in the garden, the motive power electricity. The total length of line was only 121 yards in length, having six curves of from 10 feet to 200 feet radius, and only 25½ feet of straight line. There were 62 yards of incline, ranging from 1 in 1,000 to 1 in 100. The train was composed of one pannier-engine or motor and three pannier-carriers, the weight of the three carriers being 720 lbs. each, or in all 2,160 lbs. The motor also weighed 720 lbs., consisting of:—

	Lbs.
Vehicles and organs of transmission from the secondary engine to the driving-wheels	420
Secondary engine, type D 3	180
Engineman	84
Ballast	36
	720

The electric current was produced by a Siemens machine, ordinary type D2, having electro-magnets in the circuit. This machine is driven by a pulley on the principal shaft, with intermediate gearing, with a velocity of 1,400 turns per minute. The secondary machine is run at a speed of 1,000 turns per minute; the final speed of the 10-inch driving-pulleys is 125 turns per minute, which should have given a speed of train of 5·36 feet per second. But the speed was reduced by slipping due to curves to 4·26 feet per second, or 2·90 miles per hour. The whole trip over 121 yards was made in eighty-five seconds. The speed was sensibly the same on straight lines, curves and gradients.

Experiments were made to determine the work absorbed and the efficiency. The gross weight of the train was 5,280 lbs., or

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[1] Minutes of Proceedings Inst. C.E., vol. lxxvii., p. 408.

2·35 tons; with twenty-four passengers at 99 lbs. each, the total weight was made up to 7,656 lbs., or 3·42 tons. The speed was 2·90 miles per hour, for which the electric work consumed was 10·8 HP. The net work done was 6·90 HP., making 63·8 per cent. of efficiency.

The total cost of the electric portion of the system was about £200. It would have served for a line 6 or 8 miles in length.

D. K. C.

An Electrical Arrangement for Operating Brakes on the Northern Railway of France. By L. Kohlfürst.

(Electrotechnische Zeitschrift, vol. vi., 1885, p. 22.)

On the Northern Railway of France the locomotives are fitted with an electrical apparatus, which brings Smith's vacuum-brake automatically into action. Metal brushes are fixed to the under-frame of the locomotive, and rub against a special contact between the rails. This contact is placed about 650 feet in advance of the distant-signal, and conveys a current to the brushes so long as this signal stands at "danger." In the event, therefore, of a driver overlooking a danger-signal, the vacuum-brake would be applied to the train without any aid on his part. The apparatus, which is enclosed in a metal case, consists of a Hughes' electro-magnet, composed of a powerful steel magnet with soft iron poles, each of which carries a resistance bobbin; one end of the coils is connected through the brushes to the line-wire, and the other end to earth. In its normal position the armature, which is attached to one extremity of a lever movable around a fixed axis supporting the other end, is held down by the electro-magnet. At the centre this lever is jointed to a rod working in guides, and carrying a strong helical spring, which presses the rod upwards, and tends to force the armature away from the poles of the magnet. The lower end of the rod is connected by means of a suitable joint with the injector-lever of the vacuum-brake. When a current passes through the coils of the electro-magnet in such a direction as to produce a polarity opposed to that of the permanent magnet, the magnetism of the cores is so weakened or neutralised that the armature and rod joined thereto can be raised by the spring. The upward movement of the rod causes the lever to which it is jointed to open the cock of the steam-pipe leading to the injector of the brake, thereby bringing the latter into operation. By depressing a handle, the driver can restore the rod and armature to their normal position and take off the brake.

J. J. W.

Temporary Deviation in the Dordrecht-Elst Railway, near the Zederik Canal. By A. A. Deenik.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1884–85, p. 199.)

The widening of the span of the railway swing-bridge across the Zederik canal became urgent through the progress of the works for enlarging the navigation canal from Amsterdam to the Wahal river. The existing superstructure of the bridge had to be utilized at another place, and it being thought inexpedient to interrupt the traffic on the line during the considerable length of time necessary to remove the old superstructure, widening the opening, and placing the new swing-bridge, it was decided to construct a temporary deviation. As it was necessary that the temporary bridge could open to allow masted vessels to pass, and as the time available before the deviation to be ready was short, it was thought best to construct a double drawbridge with clear spans of 28 feet each, this system requiring less time to construct than any other. The temporary approaches to the bridge were laid on piles instead of banks, the material for this being difficult to obtain, and also to avoid the great cost of the necessary removal afterwards. The Author gives the history of the work in its details, as also those of the calculations and dimensions of the structures. The Paper is accompanied by several drawings.

H. S.

The Great Transylvanian Wire-Ropeway. By T. Obach.

(Oesterreichischen Zeitschrift für Berg- und Hüttenwesens, vol. xxxii., 1884, p. 723.)

This line, which is said to be the largest example of this kind of traction as yet executed, has been constructed by the Hungarian government to supply two blast-furnaces newly erected at Vajda-hünyad with ore and charcoal. The system adopted is that of Mr. T. Obach, of Vienna, having two fixed ropes for travelling lines, and an endless hauling rope passing over horizontal guide-pulleys at either end, one of which serves as a strainer, while the other is driven by the motive power of a steam-engine. The total length of the line is 30,542 metres, the total fall is 892 metres, crossing sixty hill-summits and sixty-two valleys, including twenty-eight spans varying from 200 to 479 metres. In the latter case the line is 247 metres above the bottom of the valley, so that the laden tubs are scarcely recognizable from below, and gradients of 1 in 1½ are adopted in many places.

The line is divided into numerous sections, of which the six upper ones are intended for charcoal carrying only. These are:—

		Metres.		Metres.
I.	Vadudobri-Gruniului	2,404	Total rise	95
II.	Gruniului-Plaului	4,418	,, ,,	99
III.	Plaului-Bunila	4,276	,, fall	99
IV.	Bunila-Pojinitza	4,291	,, ,,	665
V.	Pojinitza-Ruda	1,882	,, ,,	28
VI.	Ruda-Gyalar	3,603	,, ,,	202

At Gruniului, Bunila, and Ruda stations, there are engines of 6 HP., each of which drives two sections of the line; the others are transfer-stations, and contain the stretching-pulleys. The upper terminus at Vadudobri, situated in a deep valley in the mountains, is a central receiving place for charcoal, made in piles mainly from beechwood in the numerous tributaries, which is carted to the depôt, and tipped into bins provided with mouthpieces close by valves for filling the tubs on the line. These are of half a cubic metre capacity, and carry a load of about 240 kilograms. They are coupled up to the hauling-rope, and travel down to the engine-station, where they are detached automatically, and run by rails on to the next section, and so on; on the return journey the tubs are empty. In addition to the loads of charcoal, feed-water for the intermediate engines is sent down from Vadudobri in special vehicles with cylindrical water-tanks.

At Gyalar the coal-line joins that bringing ore from the mines, which continues to the furnaces in two sections, namely:—

	Metres.		Metres.
VII. Gyalar-Catzenas	5,437	Total fall	234·5
VIII. Catzenas-Hunyadi	4,320	„ „	192·0

Catzenas is an engine-station, with a 6 HP. engine and another in reserve, as well as brake-gear also in duplicate.

The ore-tubs carry 300 kilograms, which are loaded from bunkers filled from the mine above, and are sent down in regular order, two loads of coal alternating with each load of ore. At the works they are directed by hand to the ore and coal sheds alternately, the tipping-gear being so constructed that each tub can be easily unloaded by one man. When empty they are returned continuously to the mine and coal depôt by the opposite line. The number of tubs carried is 100 per hour, of which two-thirds bring ore and one-third charcoal.

The gradients in the lower section, Gyalar-Vajda-Hünyadí, are with the load, so that when fully loaded the line is self-acting, and even requires to have the speed checked by brakes. It is only when the down-load is insufficient, or return freight has to be sent up to Gyalar, that steam-power is required.

In spite of the great differences in level on the line, the tallest strut does not exceed 27 metres in height. This is on the ore-line just below Gyalar, where a crossing of 654 metres is divided into two spans of 330 and 324 metres. It is made with a double frame, with a saddle for the carrying rope to prevent injury from bending, and a system of rollers for the hauling-rope to relieve the oblique strain upon the hanger of the tub.

The standards, as a rule, are constructed of round timber, and are of two types. Those for the heavier section of the ore-line have double posts, with the line suspended from cross-pieces above, while in the lighter sections single posts, with the line overhanging from a T-piece, are used. When more than fifteen metres high, they have diagonal wind-bracings.

The bearing-ropes are carried in cast-iron shoes, which have smooth grooves where the pressure is light, and bearing-rollers where it is heavy. On slopes the latter are placed on swinging bearings, so as to take the inclination of the line automatically.

The ropes used are of the best class of steel wire, the carriers are 17 millimetres thick on the coal-line, and 25 millimetres on the ore-line, the respective thicknesses of the hauling-ropes being 13 and 18 millimetres. The coupling-apparatus of the tubs on the hauling-rope is a very simple one, which grips the stops on the latter from above, and closes by a self-acting motion, which cannot be released during the trip either by accident or design. It has the further advantage of passing freely over guide-rollers, so that very wide spans, with rapid changes of slope, can be overcome with only a minimum of constructive difficulty in the way of standards, as is apparent from the fact that the entire line of more than 30 kilometres in length, as well as the sidings at the ore depôt, has been constructed, according to the information furnished by the contractor, for 560,000 florins, or £46,000. The Paper is illustrated by three plates of sections and details of the construction of the standards, which are not, however, specially described.

H. B.

The Arlberg Tunnel. By A. Pierre Charton.

(La Génie Civil, vol. vi., 1885, pp. 3 and 18, 1 plate and 5 woodcuts.)

The Arlberg Railway,[1] opened on the 20th September, 1884, has placed Austria in direct communication with France without having to pass through any other country except Switzerland. The tunnel through the Arl mountain, which forms the principal work on the railway, was first proposed in 1847; but though several schemes were designed in subsequent years, it was not till May 1880 that it was sanctioned by the Austrian Government; and the works were commenced in the following June. The driving of the tunnel was commenced in November 1880, and was completed three years after; and the line was opened more than a year earlier than had been anticipated. The railway going from Bludenz to Innsbrück is 85 miles long; and the tunnel, at the summit level, has a length of 6⅓ miles. The tunnel has a rising gradient of 1 in 66 from the western extremity at Langen for a distance of 4 miles, and a falling gradient of 1 in 500 for 2½ miles to St. Anton at the eastern end, as the greatest traffic will be from east to west. The rock through which the tunnel was driven is mica schist containing a variable proportion of quartz; so that in the eastern portion, where quartz predominated, the rock is very hard, approaching to gneiss, and contains very little water; whilst in

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[1] Minutes of Proceedings Inst. C.E., vol. lxviii., p. 376.

the western portion, where there is little quartz and a greater proportion of mica, the rock is very fissured, and there are veins of clay, yielding a large quantity of water. The main heading, 9 feet wide and 8¼ feet high, was driven along the bottom of the tunnel, from the roof of which shafts were opened upwards, by which a second gallery, 6½ feet wide and 7½ feet high, was driven in sections, in both directions from each shaft, so as to keep pace with the heading. The shafts were formed at intervals of 79 feet in the eastern portion, and 216 feet in the western portion, owing to the difference in the strata; and after giving access for driving the gallery, the shafts furnished a means of exit for the materials excavated from it into wagons in the heading. The work was commenced by hand, six miners boring the forehead of the heading, and four in the gallery; the base of the heading, and the roof of the gallery corresponding to the base and roof of the actual tunnel. The tunnel was enlarged to its full section, and lined, in lengths of from 20 to 26 feet; and the centering for the arch was supported by transverse beams, resting on the side benches in the case of hard rock, or on props placed on the base of the tunnel where the material was soft. The excavation of a length occupied, on the average, about twenty days; and the masonry about fourteen days. The masonry consisted generally of mica schist rough dressed; but ashlar masonry was employed where the pressure was considerable. The tunnel has a maximum width of 26½ feet, a width of 24½ feet at rail level, a semicircular arch of 13⅛ feet radius, and a clear height of 18½ feet from the sleepers for a width of 11⅓ feet. The thickness of the masonry varies, according to the nature of the rock, from 1⅔ foot as a lining for the roof and sides, up to 3 feet for the arch and 4 feet for the side walls, together with an invert, 2½ feet thick, at the bottom, as shown by ten different sections.

As at the Mont Cenis and St. Gothard tunnels, water-power was employed for executing the works; for the requisite steam-power would have entailed the consumption of 120,000 tons of coal, which, owing to the difficulties of carriage, would have cost about £240,000; whereas the establishment of the water-pressure apparatus cost barely half that sum. At the east end, by damming up the Rosanna torrent, and leading its waters into a masonry reservoir situated 433 feet above the tunnel, the water was conveyed to the machines, through a 3-feet conduit, with a pressure of fifteen atmospheres; and the power obtained amounted to 1,500 HP. in summer, but fell to less than half this quantity in winter, owing to the frosts. At the west end, the supply of water was less good, and was more difficult to lead down owing to the exposure of the site to avalanches. Three dams had to be erected for the storage of the water; and the discharge was employed in working turbines with a maximum efficiency of 800 HP. In the first four and a half months the holes were bored by hand, till the machines could be established; and an advance of 676 feet was accomplished at the eastern end, and 790 feet at the other. Sub-

sequently the Ferroux percussion rock-drill, worked by compressed air, was used at the eastern heading, and the Brandt grinding rotatory drill, worked by water-pressure, at the western heading. The different character of the rock, however, at each end rendered it difficult to compare the efficiency of the two systems. The work at the western portion was hindered, not merely by the dissimilarity of the strata, where plastic clay was sometimes found adjoining hard graphite, but also by two explosions, by the precautions necessary to avoid slips, and by the reduction of the width of the heading from 9 feet to $6\frac{1}{2}$ feet for ensuring the safety of the work. Accordingly, whilst the Ferroux drills pierced 5,785 lineal yards on the Tyrolese side, the Brandt drills only accomplished 4,960 yards on the Swiss side. The average daily advance of the Ferroux and Brandt machines respectively was as follows: $13\frac{1}{2}$ and $9\frac{1}{2}$ feet in 1881; $17\frac{1}{5}$ and $15\frac{1}{10}$ feet in 1882; and 17·85 feet and 17·82 feet in the ten and a half months of 1883. These figures show that when the nature of the rock on each side became similar, as the faces approached together towards the close of the work, the efficiency of the Brandt drill was practically equal to the other; and for several months in 1883 this machine effected an average daily advance of 19·18 feet. The Brandt machine, moreover, is superior to the Ferroux machine in expending less force, in entailing a less consumption of explosives, and in requiring only seven miners instead of twelve; so that though the Arlberg tunnel-works do not enable a final decision to be arrived at as to the comparative merits of the two machines, the results achieved by the Brandt machine afford a prospect of its being the machine of the future for the construction of large tunnels.

An incitement to rapid progress was furnished by the Austrian Government, who, whilst requiring an average daily advance of 10 feet 10 inches at each face, offered a premium of £68 for each day of earlier completion, and imposed a similar fine for each day's delay beyond the fixed period. The supply of air for ventilation was furnished by a separate conduit, as for this object an ample supply only is necessary, and not under pressure. It was also found very advantageous to clear the heading, after every blast, by injecting water in the form of a fine spray which rapidly removed the gases, smoke, and dust resulting from the explosion, and also lowered the temperature. Accordingly, the contractors provided three distinct conduits leading to each heading; one for supplying the motive-power, consisting of compressed air on the east side and water under pressure on the west side; a second supplying air at low pressure for ventilation; and a third bringing water under pressure for clearing the heading. The foul air escaped through the upper gallery; and the supply of water served in addition, at the east heading, for clearing out the holes formed by the Ferroux drill. The excavation in the tunnel amounted to about 91 cubic yards, and the masonry to 32 cubic yards per lineal yard; which are equivalent to loads of about 900 tons of excavation removed, and 350 tons of materials introduced daily at

each end of the tunnel, necessitating a daily transit of four hundred and fifty wagons in each portion. The trains of wagons were run on a temporary single road, laid to a 2 feet 3½ inches gauge, with sidings at each extremity. The various provisional works, such as the reservoirs and conduits for the water-supply, the approach-roads, the buildings for the works, and houses for the men, were supplied at the cost of the Government; but the actual tunnel-works were executed by contract. The schedule prices per lineal yard were: £11 10*s.* 5*d.* for the advanced heading, and £7 13*s.* 7*d.* for the upper gallery, for the first kilometre (1,093 yards) with an addition of 15*s.* 4*d.* and 7*s.* 8*d.* respectively for each successive kilometre; and varied for the completion of the tunnel, with the exception of the central culvert and the ballast, according to the different sections, from £30 14*s.* 5*d.* per lineal yard for the section excavated for a lining 1⅔ foot thick, but not lined at all, with an addition for each additional kilometre of £1 10*s.* 8*d.*, up to £125 4*s.* for the thickest section of masonry, together with an invert, with an addition of £5 7*s.* 6*d.* per kilometre. The type of section having side-walls 2½ feet thick and an arch of 3 feet was carried out for a total length of 7,794 yards, longer than any of the other ten different types; and its completion cost £58 7*s.* 6*d.* per lineal yard, with an addition of £3 1*s.* 5*d.* per kilometre after the first. The total cost of the tunnel was as follows:—

	Tunnel Works.	Provisional Works.
	£.	£.
West portion of tunnel (Langen) . .	548,720	61,920
East " " (St. Anton) . .	536,960	61,800
	1,085,680	123,720

Total cost (length 11,231 yards) . . £1,209,400

which amounts to £107 13*s.* 8*d.* per lineal yard.

The Arlberg tunnel compares very favourably with the Mont Cenis and St. Gothard tunnels both in rate of construction and cost, as indicated by the following Table, which clearly shows the advantage gained from the experience of previous similar works:—

Tunnel.	Length.	Duration of Boring.	Progress per Day of 24 Hours.	Cost per Lineal Yard.
	Miles.	Months.	Lineal yards.	£. s.
Mont Cenis . . .	7½	157	2·57	225 6
St. Gothard . . .	9¼	88	6·01	142 13
Arlberg	6¼	40[1] (?)	9·07	107 13

[1] This figure is put down as 10 months in the original, but is probably a misprint; and another evident misprint occurs in the gradient of the St. Anton portion, which is given as 0·02, instead of 0·002, which works out from the levels given on the longitudinal section.—L. V. H.

The Arlberg Railway has provided a fresh line of communication between the east and west of Europe; and in order to prevent a chance of its traffic being paralysed by a lowering of the rates of the St. Gothard Railway, the Austrian Government obtained an agreement with Switzerland, before commencing the works, that a similar scale of rates should be granted to both lines.

L. V. H.

On Locomotives used in the Arlberg Tunnel during its Construction.

By F. von Ržiha.

(Zeitschrift für berg- hütten- und Salinen-Wesens, vol. xxxii., 1884, p. 520.)

The completion of the Arlberg tunnel in a year less than the time originally estimated (four instead of five years) is attributed to the skilful organization of the working arrangements, and among these the methods adopted for the removal of the ground excavated, and the supply of materials required in construction, are of principal importance. The tunnel, 10,270 metres long, is driven in a straight line but with dissimilar gradients, the rise from the western end being 15 per cent. (1 in 67) for 6170 metres, while for the remaining 4,100 metres on the east side the slope is only 1 in 500, which places the summit at a point 1,085 metres from the centre. This together with the circumstance that the rate of advance was more rapid on the eastern than the western side, so that the opposite drifts met at 5,500 metres from the former point, made it necessary to take the débris formed during the later stages of the excavation up a rise of 1 in 67 of nearly a mile long, which could only be done by mechanical power.

The tunnel was constructed on the English system, the bottom drift, $2\frac{1}{2}$ metres high and $2\frac{3}{4}$ metres broad, driven by machinery at an average of $5\frac{1}{2}$ metres per day, was connected by rises of 3 to 4 square metres section, at intervals of about 65 metres, with another drift in the roof which was driven by hand-labour. From the latter the full-sized excavation was commenced, working from above downwards, the number of points of attack averaging about fifty on each side, so that an average length of 1,500 metres was in progress at one time, the masonry being finished in lengths of 5 to 9 metres as the ground was taken out. As the contract stipulated that the entire work was to be finished within one hundred and eighty days of the meeting of the ends of the opposite drifts, it was necessary to make very careful arrangements for the transport which had to be done entirely along a single line in the bottom drift. The amount of rock excavated per lineal metre of the full-sized double-line tunnel averaged 80 cubic metres of an average density of 2·8, and the lining required 29 cubic metres of 2·6 density, in addition to which the heavy loads of tools, timber, and rails, gave the net loads westwards of 90 tons and eastwards of

340 tons per metre, or at the daily rate of 5·5 metres, a total quantity of 1,815 tons net or 3,025 tons gross to be moved daily from each end, including the workmen's trains.

The gauge of the line was 700 millimetres (27½ inches); the wagons of 2·57 metres internal length, 1·18 metre and 0·53 metre high, carried when filled 2·3 cubic metres corresponding to 1·3 cubic metre of solid rock. The work was done by trains running according to a timetable, very exactly determined in advance, so that every workman knew the particular minute when the loading or discharging of each wagon must be completed in readiness for the next journey. The number of trains run was twelve each way on the east side and sixteen on the west side. The return journey in the latter case was effected by gravitation. Each train had its own conductor, and every working place a special number. The conductor when in the tunnel ascertained from the different foremen and gangers what materials, tools, and empty wagons were required at each working place by the next train. When this train was loaded up and returned to the surface, the next train, made up in accordance with these requirements, full and loaded wagons being marshalled in the order in which they were wanted, was despatched by engine power to the so-called tunnel-station, a point as near as possible to the section under construction, whence the separate wagons were taken forward by hand in the order required; the number of the working-place where it was wanted being chalked on each. Shortly before the next train was due, the whole of the wagons were brought out and collected for the engine train on the east side, or run out singly with the brakes down, on the west side.

During the latter period of the construction of the eastern side, when after passing the summit the work was done on a falling gradient of 1 in 67, the return wagons braked down separately to the bottom of drift, when formed into a train were connected by a travelling drag-rod, about 1200 metres long, supported on wagon wheels, the whole forming a skeleton train equal to the length of two hundred wagons and weighing 282 tons, which just reached across the summit. This was drawn out by three engines on the falling gradient on the other side.[1] As soon as the wagons came to the top of the bank the drag-rods were disconnected and placed on a siding until required for the next trip.

In the locomotives, constructed by Krauss of Munich, a special modification of the fireless system of Lamm and Francq is adopted. They are like ordinary tank-engines, but with extra large boilers, constructed to bear a pressure of fifteen atmospheres, so that when fired up at the surface the water may be superheated sufficiently, to furnish steam during the underground journey without further firing, the chimney being completely closed to deaden the combustion. This is called by the author the system

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[1] This arrangement is more fully described in the "Centralblatt für Bauverwaltung," 1883, No. 45.

of "suspended firing." The engines are of two kinds, whose principal dimensions are given in the following Table:—

	Nominal HP.		45	60
1.	Cylinder diameter d	c.m.	23	25
2.	Length of stroke l		30	30
3.	Driving wheel diameter D		58	58
4.	Wheel-base (four-coupled wheels)		140	140
5.	Heating-surface	sq. met.	18·01	27·59
6.	Grate-surface		0·3	0·425
7.	Steam-pressure max. p	excess atmospheres	15	15
8.	Steam-space in boiler	litres	660	945
9.	Water " max.		2,340	3,500
10.	Space for feedwater		660	765
11.	" coal		235	495
12.	Weight in running order	tons	10	14·5
13.	Greatest height	c.m.	350	350
14.	" breadth	"	210	210
15.	" length	"	435	495
16.	Tractive power at 12 atmospheres $\left(Z=\frac{0\cdot 6.p.d^2.l}{D}\right)$	kg.	1,793	2,328
17.	" expressed by p $\left(Z=\frac{0\cdot 6.d^2.l}{D}\right)p$	"	$1\cdot 642p$	$193\cdot 96p$

The special arrangements for running underground include

1. A regulator with very precise adjustments serving as a reducing valve.

2. A double-beat valve in the blast-pipe which, when, dropped, allows the exhaust-steam to pass up the chimney in the usual way, but when lifted diverts it to a special exhaust-pipe placed alongside the chimney.

3. Two Körting aspirating universal injectors.

4. The boiler is carefully covered with a non-conducting composition in addition to the ordinary sheet-iron cases.

5. Special means of completely closing chimney and ash-pan from the driving-platform.

6. A powerful and rapid-working brake, Exter's construction, and sand-box. These are placed on the right-hand side of the engine, which, as no firing is required, can be worked by one man. The whole of the driving-mechanism, as well as the driver's platform, is completely covered in.

The working limits in regard to pressure, speed, &c., are discussed on theoretical grounds, which are too voluminous for reproduction. The lowest pressure to which the steam can be allowed to fall is computed at 6·7 atmospheres for the larger, and 5·4 for the smaller engine, although in practice it does not appear to have gone below 7·2 atmospheres. The observed temperatures corresponding to these pressures were 204° C. for fifteen atmospheres initial, and 172·6° C. for 7·2 atmospheres final. The maximum load computed for the 45 HP. engine on the gradient of 1 in 500 was 117·1 tons, and 50 tons, for that of 60 HP. on 1 in 67 which appears to have been realized in practice.

The distance to which the engines can run without firing is in the first case 4·342 metres, and in the second 3,674 metres,

Number of Journey.	Direction.	Nominal HP. of Engine.	Length of Fireless Journey in Metres.	Running Time. Minutes.	Initial Pressure, p_1 Atmospheres.	Final Pressure, p_2 Atmospheres.	Adhesion Weight of Engine, M Tons.	Wagon Load, Q Tons.	Tractive Power, Z Kilograms.	Work done by Engine, μ in Metre-kilograms.	Initial Temperature, t_1 Centigrade degrees.	Final Temperature, t_2 Centigrade degrees.	λ Calories.	Water Expended, P_0 in Litres.	Total Water at commencement of Journey, P_1 Litres.	Work Realized by Steam, μ_1 Kilograms.
1	E. end, Up .	45	2,220	19	15·0	10·2	10·0	88·0	696·0	1,545,120	203·8	186·6	666·0	80·8	2,340	1,616,000
2	,, Down	45	2,260	16	10·2	7·6	10·0	180·0	580·0	1,310,800	186·6	174·5	661·5	56·1	2,340	1,122,000
3	,, Up .	45	2,260	19	15·0	9·4	10·0	87·0	689·0	1,557,140	203·8	183·2	665·5	100·0	2,340	2,000,000
4	,, Down	45	2,160	16	9·4	7·2	10·0	197·0	631·0	1,362,960	183·2	172·8	660·8	50·0	2,340	1,000,000
5	W. end, Up .	{60[1] 45}	2,780	26	{14·9 14·8}	8·9 9·7	{14·5 10·0}	70·0	1,914·5	5,323,310	{203·0 202·0}	181·0 184·0	665·0 665·4	159·1 87·5	{3,500 2,340}	4,930,000
6	,, ,, .	{60[1] 45}	2,780	30	{15·1 15·0}	7·4 7·2	{14·5 10·0}	103·95	2,591·5	7,212,710	{204·0 203·8}	174·0 172·2	664·1 663·8	214·3 150·4	{3,500 2,340}	7,294,000
7	,, ,, .	60	2,780	28	15·1	14·5	14·5	50·4	1,312·5	3,648,750	204·0	181·2	665·2	165·0	3,500	3,300,000
										21,960,79[illegible]				1,063·2		21,262,000

[1] With two engines coupled.

which for practical purposes should be reduced by about one-fifth. Supposing the smaller engine to be employed in a mine-level it would be capable, if utilizing its full adhesion, of drawing 100 tons up or 148 tons down a gradient of 1 in 800. Taking the pit tram at 350 kilograms empty, or 850 kilograms loaded, weight, this would correspond to a train of one hundred and seventy-four loaded, or two hundred and eighty-six empty trams, drawn out- or in-bye respectively for a distance of 3·5 kilometres without firing. But as such loads do not arise in practice, it is evident that either a much longer distance could be run, or smaller engines of the same kind would suffice for the work. No unpleasant effects were experienced in working either from the exhaust steam or the gases of the deadened fire. As a rule continual firing was not required in the tunnel except during the last few months of the work on the east side, when the heavy work of dragging the wagons up the dip heading made it necessary to run the engines with full firing for about 2,000 metres from the mouth of the tunnel, in order to have sufficient pressure for the work at the end of the journey.

The speed realized varied from 2·1 to 2·3 metres per second on the east side, and from 1·5 to 1·8 metre on the steeper gradient on the west side.

The useful effect realized with the smaller (45 HP.) engine was 18·3 HP. or 41 per cent., and with the larger one (60 HP.) 28·9 HP. or 48 per cent.

The favourable results obtained by these engines, is, in the Author's opinion, likely to lead to their use in ordinary mining operations, as among all the different systems of mechanical traction that by locomotives is the cheapest.

The working results obtained are contained in a final tabular statement.

H. B.

Cost of the Arlberg Tunnel.

(Giornale del Genio Civile, 1885, p. 95)

The following is a list of the prices paid for the work, reduced to English value, taking 25 Italian lire to the pound sterling:—

The establishment of shops, machinery, &c., cost £123,720, which was paid by the company, the contractor being allowed to use them.

The average cost per lineal yard of tunnel complete was £109 17*s.* 6*d.* at the western, and £92 2*s.* 6*d.* at the eastern side of the mountain, the difference being due to the geological character of the strata, which on both sides are primary rocks, consisting of micaceous and quartzoze schists; but while those on the eastern side are hard and compact, full of crystals of quartz and feldspar, and contain very little water, those on the western consist princi-

Description of Work.	Price per lineal yard. For the first 1,100 yards. £. s. d.	Increase for each 1,100 yards up to 5,500 yards. £. s. d.
Lower heading, size 9 ft. × 8 ft. 3 in.	11 8 8	0 15 3
Upper „ „ 6 ft. 7 in. × 7 ft. 6 in.	7 12 6	0 7 8
For completing the tunnel, exclusive of the culvert and ballast:—		
Unlined tunnel—excavation large enough for 1 ft. 8 in. lining	30 10 0	1 10 6
Tunnel with arch and side walls 1 ft. 8 in. thick	44 19 6	2 5 9
„ „ 1 ft. 8 in. and side walls 2 ft. 8 in. „	51 1 6	2 5 9
„ „ 2 ft. 2 in. „ 3 ft. 2 in. „	57 18 8	3 1 0
„ „ 2 ft. 9 in. „ 3 ft. 7 in. „ without invert	67 4 6	3 16 3
„ the same dimensions with invert 2 ft. 2 in. thick	83 1 10	3 16 3
„ arch 2 ft. 8 in. and side walls 3 ft. 2 in. in ashlar masonry without invert	93 0 0	4 11 6
„ the same dimensions with invert 2 ft. 2 in. thick	107 9 8	5 6 9
„ arch 3 ft. and side walls 4 ft. thick without invert	105 19 2	5 6 9
„ the same dimensions with invert 2 ft. 8 in. thick	124 5 0	5 6 9
For the masonry of the culvert according to three different types from / to	1 4 5 / 1 13 8	0 1 6
Ballast	0 11 5	0 0 7

pally of mica, are less compact, have many fissures, yield large volumes of water, and exert great pressure, requiring a massive lining of masonry to resist the thrust.

The Brandt drill was used on the western, the Ferroux on the eastern side, but the different character of the rock prevents a comparison of their respective merits.[1] The mean daily progress was

Year.	Ferroux drill.	Brandt drill.
1881	4·52 yards.	3·17 yards.
1882	5·73 „	5·03 „
1883 (10½ months)	5·95 „	5·94 „

The following is a comparison of the three principal tunnels of Europe:—

Name of Tunnel.	Length.	Time taken in Construction.	Mean daily Progress.	Cost per Lineal Yard.
	Miles.	Months.	Yards.	£ s. d.
Mont Cenis	7·45	157	2·57	223 12 0
St. Gothard	9·32	88	6·01	141 11 6
Arlberg	6·21	40	9·08	106 17 4

[1] *Ante*, p. 384.

It should be noted that the first of the three was constructed before dynamite was introduced.

W. H. T.

On the Work done in Hand-boring. By H. Höfer.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1884, p. 603.)

The Author, during his residence at Pribram, was engaged in some experiments with a view to determine the mechanical effort required in boring holes for blasting in rock by hand, but in consequence of his removal to Leoben they have not been completed. The chief point of interest consisted in the determination of the work done by the use of a specially contrived indicator. This consisted of a spiral buffer-spring with a socketed plug in the position of the buffer-plate. A bar representing the borer is placed in the socket and struck with the sledge or mallet at the other end in the same way as in actual boring. The compression of the spring due to the blow is measured by a system of levers carrying a pencil which marks the distance moved upon a drum covered with paper, the whole of this part of the apparatus being similar to that of a Richard indicator. The scale of the diagram is made by dropping weights of different sizes from a height of 1 metre on to the top of the buffer-rod when a line corresponding in length is drawn upon the paper. The whole apparatus is fixed to a thick wooden board which can be fixed by screws in any required position, upright, inclined, or inverted.

The result of the experiments, as far as they have yet gone, show that the work done by a miner of average strength and skill, using a sledge of 2·42 kilograms weight, is 4·24 metre-kilograms per blow, or 6·28 metre-kilograms per second. This supposes the direction of the bore-hole to be in the most favourable position, namely, vertically downwards. For other positions the results are as follows:—

	Downwards.			Upwards.		
Inclination	90°	60°	30°	0°	15°	30°
Comparative duty per cent.	100	76·1	61·6	49·7	37·6	32·2

A comparison of these figures with those obtained from the use of hand-power boring machines working percussively, shows the latter to be mechanically disadvantageous as the duty realized in the most favourable positions is but very little more (6·4 metre-kilograms per second) than that of hand-labour; and at an average inclination of 40° is actually less, being only 4·15 metre-kilograms, even when making allowance for the time taken up in shifting and adjusting the machine.

A series of experiments made in the mines showed that the work done per centimetre of hole 24 millimetres diameter, bored

in fine-grained crystalline schist (*grauwacke*), at Pribram, was 255·1 metre-kilograms, while in a specially hard variety of the same rock it was 504·5 metre-kilograms.

H. B.

The South-Pass Jetties, Mississippi Delta.[1]

By E. L. Corthell, M. Inst. C.E.

(Transactions of the American Society of Civil Engineers, vol. xiii., 1884, p. 313.)

A short summary is given at the commencement, of the conditions and principles of the works at the South Pass, which were commenced in 1875 and completed in 1879; and reference is made, for more detailed particulars, to the Author's "History of the Jetties," published in 1880.[2]

The discharge of the Mississippi at maximum flood is 1,210,000 cubic feet per second, and its low-water discharge 250,000 cubic feet. The discharge of sedimentary matter in flood time amounts to 2,000 cubic feet of solid earth per second. The South Pass widened out at its outlet from 700 feet to 2 miles, causing a deposit of sediment, and the formation of a bar in front. The bar had an upward slope, going seawards from the South Pass, of 1 in 400, and it advanced 111 feet annually. The inclination at the bed of the Gulf off the South Pass bar is very rapid at first, amounting to 1 in 60; but it gradually becomes flatter, so that the depth is 600 feet at a distance of 9 miles from the bar, 3,000 feet at 25 miles, and depths of 2½ miles are reached further out. Whilst the depth in the South Pass amounted to 30 feet, it was only 15 feet at the head of the Pass, and 8 feet over the bar at the mouth, before the works were commenced. There is only one tide in the day in front of the delta, and its range averages 14 inches. Till 1876, the South-West Pass, with a channel from 50 to 75 feet wide at the bottom, and a depth of only 18 feet for a length of 5 miles, maintained by constant dredging, and liable to be filled up during flood time or by storm, formed the only passage for the trade of the immense Mississippi valley. Two distinct works had to be carried out, for improving the inlet and outlet respectively, of the South Pass. The inlet channel was narrowed by mattress dykes to a uniform width of 800 feet, so as to scour away the bar at its entrance; and as the checking of the current flowing into the South Pass, amounting to one-tenth of the whole discharge, tended to divert a portion into the other passes, the balance was re-adjusted by slightly checking also the flow into the South-West Pass, and the Pass à l'Outre, with submerged mattress-sills laid

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[1] Minutes of Proceedings Inst. C.E., vol. xlvii., p. 369; vol. li., p. 361; vol. lv., p. 367; vol. lix., p. 376; vol. lxxi., p. 452; vol. lxxvii., p. 421.
[2] "A History of the Jetties at the Mouth of the Mississippi River." E. L. Corthell.

right across their entrances. The outlet of the South Pass has been deepened by projecting mattress-jetties into the Gulf, from points where the pass had a width of 700 feet and a depth of 30 feet. These jetties, forming artificial prolongations of the banks of the pass, have been placed the same distance of 700 feet apart to secure a similar depth of 30 feet. The east jetty is about 2¼ miles long, and the west jetty 4,000 feet less, their sea ends being about opposite each other. They extend into a depth of 30 feet on the seaward slope of the bar. Their construction and consolidation have been previously described.

The channel at the jetties, required by the contract with the Government, was to have a depth of 20 feet, and a width of 200 feet, with a central depth of 30 feet. The improvement in the channel has developed steadily since the commencement of the jetties. At first, the concentrated current scoured out an irregular channel with ridges, mounds, and deep hollows; but by degrees the current became regular, following the line of the jetties, and the depth uniform. During the four years that the works were in progress, the current excavated 7,607,000 cubic yards of material from the bottom and carried it seawards; and since the completion of the works in July 1879, the development of the channel has continued. According to the latest survey in May 1884, the length of the 45-foot channel, between East Point and the end of the jetties, is 3,900 feet; and the length of the 38-foot channel is 2 miles; the least central depth in the jetty channel is 33 feet, and the width of the 26-foot channel is 290 feet. Beyond the ends of the jetties there is a minimum depth of 31·8 feet; and the 30-foot channel has a minimum width of 70 feet. The length of the 40-foot channel between the jetties has been increased 2,400 feet since the survey of May 1883. The silt filling the interstices of the brushwood has preserved the mattresses from the ravages of the teredo; and the concrete blocks have secured them from disturbance by waves. For the first two years after the completion of the works, violent storms used to wash the sand over the jetties into the channel, producing a temporary reduction of depth; but the construction of lines of interior jetties has stopped this action, the intermediate space within the main and interior jetties being rapidly filled up with sediment. The latest surveys show only a slight shoaling in the path of the current beyond the jetties over a width of 1,000 feet; and though the 277,000,000 cubic yards of solid matter discharged from the river-mouths must eventually produce a general advance of the delta, the deposits now occurring on each side beyond the jetties are forming the foundations for future extensions of the jetties. The inlet channel to the South Pass has now a minimum depth of 35 feet, and its 30-foot channel has a minimum width of 275 feet; whilst the least depth throughout the South Pass is 30 feet. The improvement in depth has done away with the delays of vessels at the mouth of the river so constant formerly, and has effected an enormous reduction in the rates of transport. Formerly the outlet

through the South-West Pass was so bad that it was difficult to get a larger cargo than 20,000 bushels of grain carried by a vessel; whilst now a single vessel has taken a cargo of 144,000 bushels of grain to sea. The Author concludes by pointing out the lessons which the experience at the mouth of the Mississippi teach. They are mainly summed up in the following principles: namely, that dispersion of a current shoals, whilst concentration deepens; that the flood volume of the river, and the full volume of the tides, are the natural forces which should be utilized to the utmost, by making the training jetties solid, and raising them above flood-tide level; that the jetties should be raised high enough to prevent waves from washing sand over them into the channel; that depth obtained by an accelerated current is maintained by the same scouring action; that willow mattresses form a cheap and effective construction for training-jetties; that jetties across river-bars should be rapidly carried out to completion, to produce their due effect; and lastly, that improvement by jetties retards the advance of delta-bars.

L. V. H.

Inspection of the South Pass of the Mississippi.[1]

(Report of the Chief of Engineers, U.S. Army, 1883, part i., p. 1031, 9 pl. 2 woodcuts.)

The surveys of the South Pass during the year 1882-83, indicate that the minimum depth in the central-jetty channel was 30 feet, except for five days in July 1882; and that, with the exception of nine days in the same month, the 26-foot-jetty channel has maintained a width of 200 feet. At the date of the report (July 23, 1883) the 30-foot channel had a minimum width of 90 feet, and the 26-foot channel had a minimum width of 240 feet between the jetties, and 160 feet throughout the pass, which is the best channel that has existed since the construction of the jetties. Dredging has been carried on for only seventeen days in the year. The improvement in the 30-foot channel between the jetties is attributed to the construction of an inner jetty, 6,810 feet long, parallel to the east jetty, and about 200 feet inside it, reducing the jetty channel from 1,000 feet to 630 feet. The east jetty was injured by a cyclone, having a velocity of 108 miles an hour for five minutes, and over 80 miles for an hour, which effected the displacement of concrete blocks on the jetty, weighing 28 tons, but the inner jetty protected the channel from injury; altogether, 3,040 lineal feet of the east-jetty wall were seriously injured out of a total length of 5432 feet. The survey extends a little more than a mile beyond the ends of the jetties, covering an area of 2 square miles; and two diagrams indicate the changes in depth which have occurred during the year, and since the commencement, in twenty-one separate divisions

[1] Minutes of Proceedings Inst. C.E., vol. lxxi., p. 452.

of this area; whilst a series of diagrams in two of the plates show the alterations in the curves of depths since 1876. On the average, the change of depth and in the positions of the curves was slight during the year 1882-83; but since 1876 there has been an average decrease in depth of 4⅜ feet over the whole area surveyed in front of the jetties, and all the curves of depths have advanced, this advance being greatest in the 90-foot curve, and least in the 20-foot curve. The work at the jetties was confined to the construction of the river jetty, and the projection of five wing-dams from the east jetty. The inner jetty, consisting of two rows of piles, 6 feet apart, with willows interwoven between them, is to be eventually carried along the whole length of the east jetty. Eleven wing-dams have been built in wide places of the actual pass from 20 to 250 feet long, which have increased the depth from 26 feet to 32 feet. The channel at the head of the pass has a 30-foot channel 400 feet wide. Plans indicate the actual depth, along the whole pass and jetty channel, and beyond; whilst a longitudinal section shows the alteration in depth, between 1875 and 1882, from the head of the pass to the end of the jetties. The channels at the heads of the South-West Pass, and the Pass à l' Outre are increasing in depth; but the channels over the bars at their mouths are only 12 feet and 8 feet deep respectively.

L. V. H.

Mississippi River Commission.[1]

(Report of the Chief of Engineers, U.S. Army, 1883, part iii., p. 2111, 45 plates.)

Cross-sections, surveys, gaugings, and observations of the River Mississippi have been continued under the direction of the Commission. The bottom of the river is in a constant state of motion, and the amount of material moving along the bottom, in the form of waves, depends on the velocity and depth of the stream, and is greatest when a sudden increase in velocity occurs. These waves form a series of ridges transverse to the current. The heavier material is rolled up the flat slope of the wave, and drops into the hollow over its crest, where it remains till the travel of the wave leaves it again exposed to the current. The waves are eroded by a rapid increase in velocity of the current, and are obliterated by the deposit of sediment when the velocity is checked; but they maintain their form in a uniform current. These conditions indicate that accretions at the bottom could be formed by permeable works, and that the foundations of improvement works must be sunk below the limits of scour, as shown by the river action. Sand-bars in the channel move down stream by the gradual abrasion of their upper ends, and the deposit of sediment at their lower ends. Measurements obtained of three of these bars from the sections

[1] Minutes of Proceedings Inst. C.E., vol. lxxi., p. 449.

show that their movement down-stream, in six months, amounted to from 980 to 1765 feet. The river enlarges its cross-section as it rises, owing to the erosion of the bottom; but when the river overflows its banks, deposit takes place, which is removed again as soon as the water subsides to the level of its banks. The rate of erosion, or caving in, of banks has been measured at several points, and in one instance it has been found to amount to 770 feet annually, but the average in twenty-four other instances is only 80 feet in a year. On the Upper Mississippi, regulation works have been carried on at detached points, where the navigation is most impeded; but below the confluence of the Missouri, the river requires continuous training works, which are being gradually extended down-stream, and these works will not confer much benefit to navigation till the mouth of the Ohio is reached, as the bars below the improvements prevent advantage being taken of the better draught above.

The system which is being carried out for the improvement or the river below the mouth of the Ohio, consists in increasing the depth at low-water by narrowing the low-water channel to 3,000 feet, by light, permeable structures, formed of piles, mattresses, and brush, which induce deposit of sediment. The banks exposed to erosion are protected by brush mattresses below the low-water line, and by brush or stone or the natural vegetation above. The efficiency of such works in silt-bearing rivers has been fully tested; but experiments as to their details, to reduce their cost, are still being carried on, for their cost is a question of primary importance in a work of such magnitude. The chief item of cost is the protection of the banks. This work, at Plum Point Reach, has cost 12*s.* 6*d.* per lineal foot below water, and will cost about 37*s.* 6*d.* above, or £2 10*s.* altogether per lineal foot of bank; at Lake Providence Reach, the cost is slightly less; whilst at Delta Point, where stronger and more difficult work is required, the cost below low water has been 16*s.* 1*d.*, and £2 2*s.* 3*d.* above, or £2 18*s.* 4*d.* per lineal foot of bank altogether. These prices do not include the cost of plant. The dykes on Lake Providence Reach, for contracting the channel, with piles, foot-mats, and screen, have hitherto cost 14*s.* 7*d.* per lineal foot. It is expected that these prices will be considerably reduced when the men become more familiar with the work, and larger quantities are done. The Commission consider that the control of floods should form part of the general scheme of river improvement, especially on the Mississippi, which overflows its banks from fifty to over one hundred and sixty days in the year. As a large portion of the solid matter brought down by the river, to form bars below, is carried along near the bottom, it is evident that outlets diminish the scouring action during floods, without proportionately reducing the solid matter to be removed. Accordingly they recommend that continuous lines of levees should be formed, raised just high enough to confine frequently-recurring floods, but not high enough to prevent overflow during great floods. By this means, the maximum effect of

channel improvement would be secured, with the minimum of cost. It is intended to proceed with this system at the lowest parts of the river, gradually extending it upwards, as less temporary increase in the height of the flood-level will be produced above by this plan than would occur below by proceeding down stream. The new gaps also will be first closed, as being more liable to produce detrimental changes in the river, if left open, than old gaps, which may be presumed to have reached the limits of their effects.

L. V. H.

Revolving Excavators at the Panama Canal-Works.[1]

(Le Génie Civil, vol. v., 1884, p. 393, 1 plate and 4 woodcuts.)

Two types of excavators are at work on the Panama Canal, namely, the Gubert system from Lyons, with a chain of buckets, and the American spoon excavator, with a single large bucket. These excavators are made revolving, so that they may not only serve to enlarge a work formed slowly by manual labour, but may work expeditiously in excavating and advancing the whole of the cutting. Descriptions and illustrations are given of both types of excavators. The bucket-excavator is carried by a truck running on four wheels along a road at the bottom of the cutting, and it revolves on this truck round a central pivot and a ring of rollers. The beam carrying the chain of buckets can also be raised or lowered vertically, so as to excavate at different heights of the cutting; and it is attached to springs which press the buckets against the face of the cutting, but allow of their avoiding an impassable obstacle by being pressed back. As the shoot partakes in the motion of rotation, it is placed on a pivot, and its lower end rests on a roller which can revolve round a circular path fixed on the frame of the excavator, so that the shoot can be shifted, by means of a small chain, to the required spot over the wagon to be filled. The bucket-excavator can carry forward a trench 30 feet wide. Twenty-five buckets are filled in a minute, which, as each bucket has a capacity of 3½ cubic feet, will give 1,950 cubic yards of excavation per day of ten hours. Under favourable conditions, the daily excavation might reach in practice about 1,300 cubic yards; but the three excavators at work on the Panama Canal are excavating in a rocky cutting, where blasting has to be resorted to, so that their actual capacity for continuous work has not hitherto been fairly tested. To obtain a full amount of work from the revolving excavators, it is important to provide a good system of roads for the wagons. The 30-foot trench enables three lines to be laid behind the excavator, and the two side lines to be brought up alongside. The empty wagons are brought up along the central line, and are run in succession into the lines alongside the excavator, to replace the full wagons departing by the side-lines. In

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[1] Minutes of Proceedings Inst.C.E., vol. lxxiii., p. 421; and vol. lxxviii., p. 479.

order that the switches and crossings needed for these changes of road may not have to be disturbed each time the excavator advances, a movable platform has been designed for carrying these connections, which is borne on rollers running on the ordinary road. The platform has an inclination downwards from the excavator to the three lines behind, up which the empty wagons are drawn by a rope from the drum of the excavator, and down which the full wagons descend by gravity. The excavator draws along the whole apparatus as it progresses, so that it is only necessary to prolong the three lines; and the operation of shunting is performed without the intervention of horses.

Whereas the excavating action of the bucket-excavator is continuous, that of the spoon-excavator is intermittent, as it excavates its load and then deposits it in the wagon, being capable of performing a variety of movements with its huge bucket at the end of a long handle. The Osgood spoon-excavator, employed on the Culebra section of the Panama Canal-works, is carried on a bogie-truck running on eight wheels. The boiler and main engine are placed at the end of the truck, and the excavator, with a small engine, in front. The beam forming the handle of the bucket rests on a drum supported on the jib of a crane, hinged at the bottom and fastened to a horizontal revolving disk, and the handle can be moved backwards or forwards on the drum by means of a chain. The steel bucket, having a hinged bottom and a capacity of about $2\frac{1}{8}$ cubic yards, is fastened to the extremity of the handle, and suspended by a chain hanging from the top of the jib of the crane, so that it is readily shifted horizontally or vertically in the central plane of the crane, whilst the rotating disk alters its position laterally. This spoon-excavator, like the Gubert machine, is specially suitable for pushing forward a cutting; whereas the more common type of excavators are preferable for widening them. The American manufacturers state that the machine can fill two buckets per minute, which would give about 2,600 cubic yards of excavation per day of ten hours. Hitherto, however, the maximum excavation performed by one of these excavators in the Culebra cutting appears not to have exceeded 520 cubic yards; but the results obtained up to the present time must not be regarded as decisive tests of their capabilities.

L. V. H.

Steam Excavator with Hinged Buckets.

By Messrs. Jacquelin and Chèvre.

(Le Génie Civil, vol. v., 1884, p. 357, 1 plate and 9 woodcuts.)

This new type of excavator, designed by two French engineers, was recently tried at Fleurus, near Charleroi, with satisfactory results. The ordinary excavators have their buckets riveted on the guiding chain, so that the buckets, following the inclination of the chain, can only perform their full amount of work when

enlarging a cutting already commenced; and, as they are only pressed against the slope by their own weight and that of the chain they are liable to slide along the surface of hard soils, and to fill badly. Moreover, the chain has to be somewhat slack to enable the buckets to pass over an obstacle; and when the bucket meets an impediment, the curvature of the chain is altered, and the buckets are shaken and drop some of their load; so that these machines rarely accomplish half their full work. Some more recent types move along the bottom of the cutting, and can enlarge or extend a cutting; but, owing to the rigid attachment of the buckets they cannot excavate to a great height, or must undermine the cutting, in which case the falls of earth impede their working. Experience has shown that the new type of excavator can work either by enlarging or extending the cutting, in running along the bottom where roads are readily laid. Its work is continuous; it can excavate a cutting straight forwards, for a single line of way, 33 feet high; its buckets are fully filled, and it provides space for the rapid working of its attendant wagons. The frame carrying the chain of buckets is placed at the front end of its carriage, and turns on a horizontal axis round a complete semicircle; so that the machine excavates a semicircular cutting in advance, and can complete a cutting, 21 feet wide at the base, with slopes on each side, as it advances. The carriage in the centre leaves space for a row of four wagons on each side, running on a 3¼ feet gauge. The buckets are hinged on a horizontal steel axis interlacing the two chains, so that they can assume different positions, which are limited by two pairs of stops, fixed on each side of the bucket, coming alternately against the chain, according to the situation of the bucket. Each bucket has a roller at its lower end, which rolls along a slightly curved bar, and keeps the bucket pressed against the cutting during the process of excavation, as the bucket gradually rises to an upright position. The roller leaves the bar as the chain turns round the upper drum of the frame; but the bucket is still maintained in its upright position by the upper pair of stops as it travels horizontally towards the hopper, till, on reaching another drum over the hopper of the shoot, it is tilted over, and discharges its contents. The bucket then falls into a downward position, where it is retained by the other pair of stops, with its roller in place for rolling again on the bar as soon as the chain leads it past the bottom drum to perform a second excavation. An iron plate is placed across the two chains in front of each bucket, so as to retain the heaped-up load of earth and facilitate its discharge. In the excavator which is at work in Belgium, the buckets have a capacity of 2¼ cubic feet, the chain travels one foot per second, and passes 15 buckets in a minute, giving a theoretical excavation of 73 cubic yards per hour; but in practice the amount of work is always from 78 to 85 cubic yards, owing to the piling-up of the buckets. The daily cost of working the excavator, including maintenance, capital charges, &c., amounts to £3 12*s*.

L. V. H.

Hydraulic Canal-Lift at Fontinettes.

(Le Génie Civil, vol. vi., 1884, p. 101.)

The design of this lift having been described in vol. lxvii., p. 451, this abstract will deal only with alterations in the construction of the rams, which have been introduced during the progress of the work. The lift is double, each trough being 131 feet long, 18 feet 4 inches wide, and 6 feet 7 inches deep. The hydraulic presses have an internal diameter of 6 feet 9 inches, a stroke of 43 feet, and work under a normal pressure of 25 atmospheres. It was originally intended that these presses should be made of cast iron 4¾ inches thick, giving a tension of 1·6 ton per square inch, but the Administration of Ponts et Chaussées considered this too high a strain, and ordered that the thickness should 5½ inches, and that the cylinders should be surrounded with hoops of wrought iron put on hot. Just as this was settled there occurred the accident to the Anderton lift, of which this at Fontinettes was practically a copy on a much larger scale. The two cast-iron presses 3 feet in diameter, working at their ordinary pressure, burst without any apparent cause. Upon this it was determined to abandon the idea of employing cast iron for the cylinders. Rings of cast steel were tried. A number were cast, and one picked out at random was tested, which broke under a strain of about 10 tons per square inch, whereas it was expected to stand about 32 tons. Cast steel was therefore abandoned. Wrought iron was then tried; a segment 6 feet 9 inches in diameter and 6 feet 7 inches high was constructed of plates 1·18 inch thick and tested. When the pressure exceeded 30 atmospheres numerous leakages occurred at the joints. The strength was sufficient, but the work was not watertight. Steel plates were then tried, but with no better result.

It was then resolved to divide the problem into two parts, to obtain strength by an external cylinder, and watertightness by a flexible and watertight lining; the former was composed of rings of steel plates 2·16 inches thick, 5½ inches high, placed one upon another, kept in place by a fillet at the top, of one ring fitting into a groove in the bottom of the next. To prevent longitudinal extension, tie-rods were passed through bosses in the bottom plate and the top ring, and screwed up. The tensile breaking-strength of the steel is 38 tons per square inch, with extension at the moment of rupture of 12 per cent. of the original length. A cylinder built up as described would bear a strain of 300 atmospheres. To ensure watertightness, a lining of copper nearly $\frac{1}{10}$ of an inch (0·0025 metre) thick is beaten against the sides of the cylinder.

A test cylinder as above described and 5·9 feet high was constructed and tested to 170 atmospheres, without a trace of leakage and without any permanent elongation of the steel rings.

W. H. T.

Lengthening of the Locks on the Bourgogne Canal.

By H. Bazin.

(Annales des Ponts et Chaussées, 6th series, vol. ix., 1884, p. 450.)

The locks on the Bourgogne Canal, one hundred and eighty-nine in number, were constructed at two different periods, ranging between 1775 and 1832, and of varied types. Their length was only 98½ feet, and their upper sills were at different depths. A law was passed in 1878 for increasing the length of the lock chambers to 126½ feet, and this work was completed in 1882, the upper sills of all the locks being brought to a uniform level of 7⅓ feet below the water-level of the upper reach. A lateral sluiceway was also constructed at each lock, running along the whole length of the lock-chamber, which could be put in communication with the upper or lower pool and the chamber. The lengthening was in almost every instance effected at the upper end of the lock; and it was performed during the annual closure of the canal in the four years from 1879 to 1882, as many as seventy-seven locks having been lengthened in 1881. The total cost of the works amounted to £284,700, or about £1,506 per lock. The work at the different groups of locks occupied from fifty days to nearly three months, averaging a period of sixty-six days. Two advantages have been gained by the works, viz., that boats of one-third greater tonnage can navigate the canal without increase in draught, and that the canal is now accessible to barges of the north and east. Steamboats, 125 feet long, have been specially built for the canal, and carry freights between Paris and Lyons in ten days; and the barges from the north and east, averaging 115 feet in length, have begun to use the canal; so that, in spite of the commercial depression, the traffic on the canal has doubled. The new types of boats on the canal, drawing from 4¼ to 4½ feet, carry loads of from 200 to 220 tons; and the steamboats sometimes have a draught of 5¼ feet. The depth of water over the sills is maintained at 6 feet. The increase in traffic has been mainly in the more valuable and perishable class of goods, which are conveyed by steamboats, or by boats drawn by regular relays of horses. The steamboats pass through the canal in six days, performing a journey of 25 miles per day besides passing through thirty-two locks. The other boats of the accelerated service occupy seven days in traversing the canal, accomplishing 21 miles, including the passage of twenty-seven locks, each day. The augmentation of traffic, under unfavourable conditions of trade, is due solely to the lengthening of the locks, as the deepening of the canal to 6½ feet is still incomplete, and many smaller improvements are needed to facilitate the transit of the new class of boats. The results, however, show what advantages may be gained by perfected water-communication.

L. V. H.

Description of an Automatic Inundation-Sluice.

By T. Strootman.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1884–85, p. 215.)

In many cases it is desirable to raise the lower depressions and holes behind the dams of embanked lands, and to silt these up by taking in water containing mud in suspension from the sea or tidal streams, through a tunnel or opening in the enclosing bank. After the matter in suspension has settled, the clarified water is then run off again. It is not always expedient to flood the higher parts of the lands, nor possible always to attend to the closing or opening at the proper time of the tide, during the day or the night. The opening and closing of the inlet is therefore done automatically. The door of such a sluice is made to pivot round a horizontal hinge, and when open rests on the ground. It is weighted so as not to float up, and attached to its top, by chains, is a hollow metal cylinder. The length of these chains is so arranged that when the tide rises above a certain level, the floating cylinder pulls by the chains on the door and lifts it off the ground. The current flowing into the tunnel, getting under the door, then lifts it to a vertical position, and pressing it against the sill and sides, closes the opening and keeps it shut against the higher outside water. When this falls again below the level of the inundation water, the pressure from inside, being greatest, opens the door, which, falling on the ground, allows the clarified water to run off. To guard against the cylinder drifting between the door and the sides of the opening, it is attached by a chain to a stake outside. Silting-sluices on this principle have now been used with success for several years past, principally in the province of Groningen.

The Paper is accompanied by a drawing.

H. S.

Hydromotor with Parachutes. By E. Pierron.

(Le Génie Civil, vol. v., 1884, p. 359, 1 plate and 5 woodcuts.)

The great motive power of rivers is hardly utilized at all owing to the low efficiency of water-wheels in a moderate current in consequence of the small amount of fall. The size of such wheels cannot be greatly increased; so in order to obtain a greater force, the power of the stream must be utilized over a larger distance, as the current soon regains its original velocity after passing the paddle of the wheel. The hydraulic chain of paddles of Mr. Roman, which was tried on the Seine in 1865, was an application of this principle. It consisted of two endless chains turning round two drums supported between two long barges floating on the river, to

the links of which were attached a series of seventy paddles, each $16\frac{1}{2}$ feet long and 2 feet wide, placed 5 feet apart. Mr. Roman had found that, for paddles thus spaced, the pressure on the hind paddles was three-fourths of that on the front one. The efficiency, however, of the apparatus is considerably reduced when the velocity of the current is less than $3\frac{1}{4}$ feet per second; and unfortunately the flow of the Seine did not exceed $1\frac{1}{2}$ foot per second during the whole time of the trial, reducing the efficiency to 60 per cent.; but with an adequate velocity, this machine might provide several hundred HP. at a reasonable first cost, and with a very moderate expense for maintenance. The parachute hydromotor of Mr. Yagn, though different in construction, is based on the same principle. Two endless hemp cables turn round a wooden drum supported between two barges. A series of parachutes of sailcloth are placed on the cables, at intervals apart of double their diameter. These parachutes open when going with the stream, being prevented from turning inside out by six small cords encircling them and attached to the cable; and they close on their return. The open parachutes, taking a slightly diverging course on leaving the drum, turn round pulleys at the end of their journeys, which are fixed in frames and kept in place by a float and weights. Deep grooves are formed for the pulleys by curved metal rods, so as to reduce the friction and the wear of the parachutes. Experiments on the Neva, at St. Petersburg, showed that the closed parachutes rolled easily round, and that their resistance in returning was only about 1 per cent. of the power obtained in their descent. The tension of the cables is maintained by attaching a short cable to the frame of each pulley, furnished with some parachutes, and terminated by a board placed obliquely in the stream. The trials on the Neva and at Lyons show that the action of the current on all the parachutes is the same as on the foremost one, provided that the interval between them is four times their diameter, or even with an interval of two diameters if the cables are inclined ten degrees to the current. The specific gravity of the cables with parachutes so little exceeds that of water that they readily float under the action of the current, and so they can be given a course of from 1,300 to 1,650 feet. The practical diameters of the parachutes range between 2 feet and $6\frac{1}{2}$ feet. The cable can work under the ice; it is unaffected by wind or waves; and as it is perfectly flexible, and can be sent to any depth, no impediment is offered to navigation beyond the space occupied by the barges. The whole apparatus can be taken up in an hour for removal to another part of the river. The first cost of the apparatus is small; but the renewal of the cables and parachutes forms a heavy charge, as they are reckoned to have a minimum life of only four months. The cost of the parachutes is proportional to the HP. obtained in a given velocity of current; but the cost of the cable, for a given diameter or parachute, regulated by the depth of the river, is dependent on its tractive force, which is nearly proportional to the square of the HP.

developed. Accordingly, the economical limit of application of the system would be soon reached with low velocities of current, and would depend on the frequency of renewals of the cables and parachutes.

L. V. H.

The Mean Sea-level of the Zuider Zee. By T. T. Roelants.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1884–85, p. 210.)

The Author compares the high- and low-water levels observed during eighteen years at six stations in the Zuider Zee, and calculating the mean sea-levels from those registered, concludes from the results that the mean sea-level of this gulf was nearly constant over the period of observation, not showing a tendency either to rise or fall, as compared to fixed points on shore. The Paper contains Tables, showing the mean high- and low-water levels during the years 1865–82.

H. S.

Harbour-Works at Reunion Island.
By Messrs. Joubert and Fleury.

(Mémoires de la Société des Ingénieurs-civils, 1884, p. 484, 3 3 pl.)

The new harbour of the French colonial possession of Reunion Island is situated at Pointe de Galets, on the north-west shore of the island, which is sheltered both from the trade winds of the summer months and from the cyclones of winter. The site, moreover, possesses the advantages of a stable beach, facilities for extensions of the port, and a central position in relation to the railway, which has been carried on simultaneously with the harbour works. The works consist of an entrance-channel, protected by two converging jetties or breakwaters, leading into an outer harbour, which communicates by a short channel with an inner basin with two branch docks. The curved breakwaters start from the beach above the reach of the highest tide, at a distance of 738 feet apart, and converge to a width of 328 feet between their pierheads, which extend into a depth of 40 feet. The entrance channel is 886 feet long, and 460 feet wide at its inner portion; and it opens into the outer harbour, which is 820 feet square, and was originally intended merely to reduce the waves; but it has proved sheltered enough for vessels to carry on operations in it. The canal connecting the outer harbour with the inner basin is 492 feet long, and has a bottom width of 72 feet, with side slopes of 2 to 1. The inner basin is 755 feet long, and 426 feet wide, which is to be increased to 656 feet to accommodate the large steamers that have called at Reunion since 1881. The two branch docks—opening out of the inner basin, and separated by a wide projecting quay—are each 656 feet long, and 236 feet wide at the

water-level, with side slopes of 2 to 1, over which jetties project for the loading and discharge of vessels. Each side of the central quay is furnished with a line of sheds, whose basements are on a level with the branch dock, wharves in front, and whose upper floors correspond with the level of the railways on the quay at the back. The total excavation required amounted to 2,600,000 cubic yards, of which the portion above the water-level was excavated in the ordinary manner, or by excavators; whilst the remainder, less than one half of the whole, was dredged by aid of three dredgers. The largest dredger could excavate to a depth of 30 feet, and removed 314 cubic yards per hour; and the material was deposited in the open sea from hopper barges. The breakwaters, protecting the entrance to the port, formed the most interesting and important part of the works. They have been constructed on the sloping-block system in unconnected sections, as adopted by Mr. Parkes at Manora[1]; but they differed from that work in some essential particulars. The blocks rest upon the bottom, instead of on a rubble base, and they are of much larger dimensions towards the top; each breakwater is protected at its base, on each side, and at the end, by rows of blocks; and as it is about double the width of the Manora superstructure (47½ feet as compared with 24 feet), the travelling Titan was made capable of revolving on a central pivot, to enable it to reach over sufficiently sideways to lay the side blocks, as well as those directly in front.[2] The concrete for the blocks was composed of one-ninth part of Portland cement, about one half of basaltic sand, and the remainder broken lava and basalt. The root of each breakwater, extending down the beach to 26 feet from mean low-water mark, consists of concrete-in-mass deposited within frames, 6½ feet high and 34½ feet wide, increasing to 47½ feet in width near its junction with the main breakwater. The breakwaters are built of a series of parallel cross rows of sloping concrete blocks. Each row, or section, is composed of from two to five courses of blocks, according to the depth; the bottom course contains five blocks, whilst the other courses have only three blocks, extending however across the same width of 47½ feet of breakwater. Each section rests at an angle of 71½° on the preceding one, and has a thickness of 8½ feet. Three to six lines of 60-ton concrete blocks form an apron at the base of the breakwaters, to protect them from scour. The under face of the base blocks was shaped at an angle to lie flat on the bottom, which was levelled by divers; but the upper face and the faces of the other blocks were made rectangular, similar in these respects to the Manora blocks. As the breakwaters, though composed of parallel sections, had to form a curve of 820 feet radius, each successive section was laid so as to protrude slightly seawards,

[1] Minutes of Proceedings Inst. C.E., vol. xliii., p. 4.

[2] A Goliath has been designed and is being employed by Mr. P. J. Messent at Tynemouth Harbour with a similar object ("Harbours and Docks," L. F. Vernon-Harcourt, pp. 118 and 320, and Plate 8, Fig. 8); but it is only adapted for lifting blocks of 40 tons, at a distance out, however, of 75 feet.—L. V. H.

so that the centres of each section might lie on the curve; and only the sections at the extreme ends of the breakwaters were made radial to the curve. The bottom blocks contain 21 cubic yards, and weigh 42⅓ tons, owing to their high specific gravity of about 2·7, which is due to the density of the basalt used in their manufacture. The upper blocks are 11 feet 9½ inches high: the two side blocks are 16 feet 5 inches long, containing 57⅓ cubic yards, and weighing 113 tons; and the centre block is 14¾ feet long, containing 50 cubic yards, and weighing 102⅓ tons. The top course by its weight alone could resist a force of 6,440 lbs. on the square foot; and allowing for friction, it appears that the Reunion breakwaters possess ample stability, as evidenced by their having sustained the blows of the waves in storms without the slightest dislocation. The top of the breakwater is only 8 feet above the mean sea-level, but the parapet wall on the outer side is 20 feet above. The large blocks were not used till five months after their manufacture, and the small blocks for three months. The Titan employed for depositing the blocks was formed by two lattice girders tied together at the top, at their extremities, by two cross-girders, and strongly braced together at their base. A carriage with the lifting-gear ran along rails on the top in front; and a steam-engine was placed at the extremity behind. Wheels under the Titan provided for its motion backwards and forwards along the breakwater; but it could be also turned transversely, by being slightly lifted on a central hydraulic pivot and turned by chains, right or left, worked by hydraulic presses. The Titan weighed 300 tons, and the suspended block might weigh 110 tons; but this whole weight was readily turned, the carriage holding the block being brought to the centre during the operation, and the blocks could be deposited in position to within a centimetre (⅓ inch). The Titan, when depositing, rested on hard wood blocks; and it could lay blocks of 40 tons at a distance of 42½ feet out from the front supports, and the 113-ton blocks 22⅓ feet out. The work was much hindered by rough weather, the bottom blocks being frequently displaced before the upper blocks could be laid. The depositing of the 16,470 cubic yards of blocks for the southern breakwater occupied 18½ months; whereas the north breakwater containing about 18,850 cubic yards of blocks, being sheltered by the other, was completed by the end of 1882, having occupied only ten months in construction.

L. V. H.

Removal of Sunken Rocks in the Harbour of Palermo.

(Giornale del Genio Civile, 1884, p. 477.)

The object of these operations was to widen the entrance-channel and to deepen the basin of the harbour. After a few trials it was found that, owing to the nature of the rock, surface-charges of dynamite would not answer, nor would the system of working in

pneumatic caissons be suitable, owing to the roughness of the sea at the entrance to the harbour. As the depth of rock to be removed was not great, the plan of driving headings into it could not be adopted. The best plan was found to be to drill holes in the rock from a wooden raft, 65 feet long and 32 feet broad, supported by sheet-iron caissons, and held in position by six anchors.

The rock (of the pliocene formation) is tufaceous, and is covered with a siliceous crust, in some cases 2 feet thick, which varied much in hardness and toughness. This crust was broken through by steel-tipped iron bars weighing 176 lbs. each, worked up and down in a cast-iron tube by five men. When the hole had been driven through the crust, the remainder was bored by a 4-inch rotary drill worked by a machine. The character of the rock varied to such an extent that sometimes the steel tips of six bars were destroyed in drilling one hole, whereas the same tools and the same labour were sufficient in other places for six holes; and with the rotary drills a depth of 2 feet 2 inches would in some places be driven in an hour, in others in a day. The holes were driven 1 metre apart, from twenty to fifty being bored in a day. The cartridges and fuses are described in the Paper. It was not necessary to move the raft from its position when the charges were fired. When the blasting was thought to be finished, the work of clearing away the débris was commenced, and as, during its progress, it was found that pieces of rock were still standing above the proposed surface-level, blasting was resumed at these points. On the completion of the work the minimum depth of water all over the entrance to the harbour was 23 feet.

When this part of the operation was finished, preparations were made for increasing the depth of water in the harbour. The sand overlying the rocks was first removed by a steam-dredger.

A kind of pontoon-raft was constructed, having at each corner a mast which served as a guide to a 12-inch cast-iron pile. The raft was floated out to any required position, and the four piles were then lowered till they rested upon the bottom, and water was then admitted to the pontoons. The raft thus was in the position of a solid table supported upon four legs, and when it was desired to remove it, the water was pumped out of the pontoons and it floated. Ten minutes sufficed to move it from one position to another. Four drilling machines (the drills being 3¼ inches) were fixed to the side of the raft, and driven by a 10-HP. boiler. The cartridges were of dynamite. The raft was moved to a distance of about 16 feet from the holes before the shots were fired. When the work was commenced from ten to fourteen shots were fired in a day, but as the men got used to their work the number was increased to an average of twenty-eight, and was sometimes as high as forty. The depth of the holes was from 3 feet to 6 feet 6 inches. The number of men employed was eleven. The débris, except in some few places where the explosions had not broken the rock up small enough, were removed by the steam-dredger.

W. H. T.

Experiments on the Flow of Water in a 48-inch Pipe.

By F. P. STEARNS.

(Transactions of the American Society of Civil Engineers, vol. xiv., 1885, pp. 1–18.)

These experiments are part of a series made at the Boston Waterworks. The pipe was of cast-iron, coated with coal tar. The pipe had only two bends of 500 and 1170 feet radius. The pipe had been laid three years, but the tar-coating was nearly as good as when new. The discharge was measured at a weir 10 miles distant, $\frac{3}{10}$ of a cubic foot per second being added to allow for filtration into the conduit. The loss of head was measured in a length 60 feet less than the length of the pipe to avoid including loss at entrance. The pressure was taken in a smooth brass tube, laid along the pipe, with holes in its top, and its end plugged. Four experiments gave for the coefficient in the formula

$$v = c\sqrt{r\,i}$$

mean velocity	= 4·966 feet per second	
mean coefficient	= 142·11	„
mean value of $r\,i$	= 0·001221	„

A comparison of this result with that of ordinary formulas shows that they give results 35 to 45 per cent. lower.

D'Arcy's coefficient for a clean cast-iron pipe of this size is 112·6, or 26 per cent. less than the result above.

W. C. U.

Experiments on the Motion of Water in Pipes, especially Siphons.

By WILHELM VODICKA.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 1884, p. 324.)

In spite of many observations the nature of the resistance attending the motion of water in pipes is still far from clear. It is known that the resistance increases with the length of the pipe, and with the diminution of the diameter, and the formula of Weisbach (1) is generally used for determining the velocity of outflow

$$v = \sqrt{\frac{2\,g\,h}{1 + \eta_o + \eta\,\frac{l}{d}}} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

and

$$h_2 = \eta\,\frac{v^2}{2\,g}\cdot\frac{l}{d} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

represents the loss of head due to the frictional resistance. The Author had the opportunity of making a series of experiments

upon a large siphon belonging to the waterworks of Romeno in Nonsthal. These experiments show that the resistance is influenced not only by the velocity of flow, the diameter and length of the pipe, but also to a great extent by the hydraulic pressure on the sides of the pipe. It is a physical fact that the resistance in a pipe full of flowing water does not arise from friction against the pipe itself, but against a thin layer of water which adheres to it. The thickness of these layers, which are quite still or move very slowly, depends on the pressure upon the sides of the pipe. The greater this is, the thicker will be the layer, and therefore the smaller will be the diameter of the free area for flowing. In pipes with a constant or slightly varying fall, the line of hydraulic pressure is about parallel with the pipe. In such a case the pressure is almost the same in every part, and the resistance may be taken as proportional to the length. It is different in the case of a siphon, when the hydraulic pressure varies very much.

At the Romeno waterworks the supply is collected from some springs and from the Ruffré stream into a tank, whence it goes into a masonry and concrete conduit by many curves along the faces of the hills and cliffs, for a distance of about 15 furlongs, to Cavareno, where is a second tank. From this it passes by means of a siphon 938·8 yards long across the Moscabia valley into a third tank, whence it flows on to Romeno along a second conduit about 15 furlongs in length.

The siphon consists of cast-iron socket pipes, 5 inches internal diameter, and has an outlet at the lowest point. In the experiments the water was collected at its outflow in gauged receivers, and more water was always brought to the upper end of the siphon than it could take. Three sets of experiments were made, I., II., III., by admitting the water at three points in the siphon on one side of the valley, and letting it off at three points on the other side. In I., where the head was 4·233 metres (13·89 feet), and the length 553 metres (1814 feet), the mean of three experiments gave a flow of 8·867 litres per second (117·2 gallons per minute), equivalent to a velocity of 0·651 metre per second (2·136 feet per second), whereas the Weisbach formula gives a velocity of 0·895 metre per second.

In II. the head was 7·1 metres (23·29 feet), and the length 517·2 metres (1697 feet). The mean of five experiments (varying from 8·526 to 8·645) was 8·567 litres per second, equivalent to a velocity of 0·63 metre per second, whereas the formula gives a velocity of 1·227 metre per second.

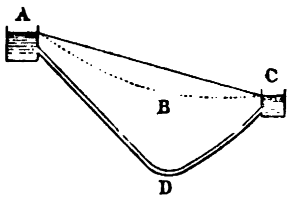
In III. the head was 19·935 metres (65·405 feet), and the length 858·4 metres (2816 feet). The experiments each gave a flow of 20·25 litres per second, equivalent to a velocity of 1·487 metres per second, whereas the formula gives 1·645.

In such experiments it is important that the gauging should not be commenced until the water has been flowing for some time, or until the bubbles caused by the compression of the air, when the water first flows into the bottom of the bend of the siphon, have

ceased to rise. For instance, in the third experiment it was almost half an hour before the bubbles ceased, and a measurement made at first gave only 13·5 litres per second, as compared with the later flow of 18·55 litres.

In every case the outflow of water varies considerably from the amount given by the formula, especially in II., where the head is greater and the sum of the hydraulic side-pressures smaller than in I., and yet the outflow is less. This may be explained as follows:—By the increased head in II. (in comparison with I.) the velocity would be increased, thus the hydraulic pressure would be somewhat lessened, as also would the thickness of the layers of water adhering to the wall of the pipe. The loss of head from friction would, however, be greater, being proportional of the square of this increased velocity. In this way almost the whole of the excess of head in II. over I. is used up. It is clear that the water cannot flow out with less velocity in II. than in I.; therefore since less water has flowed out the area of the outflow must have been less, which agrees with the fact that the outflow lies lower than in I., and there is therefore a greater wall-pressure. This indicates that the diminution of the cross-section occurs through increased wall-pressure by the formation of layers of still or almost still water on the wall of the pipe.

In III., with a head of 21· metres, the flow of water is greatly increased, and agrees fairly with that arrived at by using the formula, the increased head having overcome the resistance met with.



From what goes before it follows that the loss of head in pipes is some function of the sum of all the hydraulic side pressures, that is a function of the area ABCD (diagram) or approximately of the area ACD, included between the pipe and the straight line joining its ends.

Substituting in formula (2) F for l

$$h_2 = \eta \cdot \frac{F}{d} \cdot \frac{v^2}{2g} \quad \ldots \ldots \ldots \quad (3)$$

Where d is the diameter of pipe, v the velocity of outflow, and F the area ACD in square metres; and from (1) substituting F for l—

$$h = (1 + \eta_o)\frac{v^2}{2g} + \eta\frac{F}{d} \cdot \frac{v^2}{2g} \quad \ldots \ldots \quad (4)$$

The influence of bends is left out of consideration. Applying this formula to the data obtained from experiments I., II., III., and a fourth made subsequently with a head of 16 metres, the value of the coefficient η is determined in each case, and a curve con-

structed showing the varying values of η as h increases, which gives the following results:—

$h =$.	1	2	3	4	5	6	7	8	9	10
$\eta = 0 \cdot 00$	05	11	20	34	58	74	79	80	77	70
$h =$.	11	12	13	14	15	16	17	18	19	20
$\eta = 0 \cdot 00$	61	51	41	33	26	20	16	135	12	115

The Paper is illustrated by a number of diagrams and plans.

W. B. W.

On the Sources of Pollution in Storage-Reservoirs.

By A. Harvey Tyson.

(Proceedings of the Engineers Club of Philadelphia, February 7, 1885.)

The Author stated that, during the construction of the dam of Antietam Lake, which has a storage capacity of 90,000,000 of gallons, there was a perceptible increase in the impurity of the water-supply of Reading, Pa. This was attributed to the fact that the banks of the streams whose waters were to be impounded, and which pass through the dam, had been cleaned and grubbed. The bad taste and odour lasted three weeks, and then ceased. Next year, in the month of August, the same evils presented themselves in a worse form; the smell was the same, but the taste had changed, and resembled that of fish-oil. Thinking that some filth had been deposited in the mains, the flush-valves were opened, and various efforts were made without success to remove the impurities. An examination of the cause of the trouble showed that the tint of the water had changed from the natural blue-green to a bright green, and that, when left standing, the impurity rose to the surface and discoloured it. Throughout the ten weeks that the smell and taste remained, whenever the thermometer sank below 65° to 70° for more than a day, the impurity temporarily disappeared, to return when the temperature exceeded 70° or 75°. The contamination was discovered to originate in a vegetable growth, which only became offensive in its decay. In each succeeding year the growth has returned, and the Author has, by means of correspondence, discovered that in upwards of a hundred localities where water is impounded, the same trouble has been experienced. Various plans have been proposed to remedy the evil, among which aeration by flow in open channels, and even the gigantic scheme of roofing-in the reservoirs, to exclude heat and light, are mentioned. It was

suggested in the course of discussion on the Paper, that in deep reservoirs the products of decaying vegetation sink to the lower water, where decomposition is suspended for want of oxygen, and that the decay is renewed in the mains. As a prevention, surplus water should be wasted from the bottom of deep reservoirs, and not over the weirs. It was also pointed out that the state of the large fresh-water lakes, where the circumstances were analogous, should be inquired into, and samples of water should be obtained from various depths.

G. R. R.

Colmar Waterworks. By Messrs. Burghardt Brothers.

(Bulletin de la Société Industrielle de Mulhouse, 1885, p. 130.)

These works were laid out according to the indications, and under the direction, of Mr. Gruner. The pumps, engines, and boilers were constructed by the Authors. For the service of the population of Colmar, 25,000 inhabitants, it was decided to provide a daily water-supply at the rate of about 53 gallons (240 litres) per head, amounting to 6,000 cubic metres, or about 8,000 cubic yards, per day; equivalent to 2½ cubic feet, or 15·6 gallons per second (about 70 litres), the specified rate of delivery.

There are two 10-inch pumps, side by side, horizontal, direct-acting, each connected to one steam-cylinder, condensing, connected to one crank-shaft and fly-wheel. The steam-cylinders are 17·7 inches in diameter, steam-jacketed, with a stroke of 31½ inches, making from fifteen to thirty-five revolutions per minute, against a total calculated head of 187½ feet of water. The normal speed is thirty revolutions per minute. Steam is supplied from two boilers of the usual French type, one only working, the other in reserve, having each 18 square feet of grate-area, and 425 square feet of heating-surface, with, in addition, 516 square feet of feed-water heating-surface in forty-eight pipes. The authorized pressure is 6½ atmospheres.

Collmann's valve-gear is employed, having equilibrium-valves. The steam is cut off at from 0 to 65 per cent. of the stroke. A high-speed governor is employed, by a special arrangement of which, the speed may be varied according to the demand for water. The plummer-blocks of the fly-wheel-shaft are in four pieces, with bronze bearings adjustable laterally. The condensation-water is pumped, with a portion of the condensing-water, into the boiler. The feed-pumps, one to each engine, are so proportioned as to supply exactly the quantity of water necessary at the normal speed. The fly-wheel is 13 feet in diameter, and weighs 6 tons; it is sufficient to ensure uniform motion even for high degrees of expansion, and whilst working with one engine only. The air-pumps are constructed with plungers.

The pumps are horizontal, double-acting, made with plunger-

pistons, which, if well made, though expensive at first, possess the greatest efficiency of delivery. The pistons are not packed, and depend for tightness on accuracy of fit. Having a coefficient of 0·9 for the delivery of the pumps, their dimensions were calculated accordingly. The suction-pipes are 10¾ inches in diameter, to suit a velocity of flow of about 2 feet per second; and the discharge-pipe for the two pumps is 8¾ inches in diameter, giving a velocity of flow of 3 feet per second. The main delivery-pipe conducting the water to the reservoir, at a distance of 3,280 yards, is 13¾ inches in diameter. The pump-valves are on the Thometzek system, cylindrical, in four stages, giving a wide combined thoroughfare with very little lift. The seats and valves are of cast-iron, the latter being faced with india-rubber. The uppermost valve is 6 inches in diameter inside, and 12 inches outside; the remaining three are 10¾ inches inside, and 16¾ inches outside, in diameter. The lift is only ⅓ of an inch.

From the results of a trial lasting six hours twenty-four minutes, made four weeks after the pumps were started, it appears that the pumps delivered, at each stroke, a volume of water 98 per cent. of their working capacity. The total lift was 187¾ feet, representing 60½ HP.; whilst the indicator power of the engines was 78½ HP., showing an efficiency of 77 per cent. Allowing 90 per cent. of efficiency of engine-power at the fly-wheel-shaft, the efficiency of the pump in itself would be 85 per cent. The consumption of steam was at the rate of 19 lbs. per indicated HP. per hour.

The Paper is illustrated by two plates of the engine and pumps.

D. K. C.

The Separate v. *the Combined System of Sewerage.*

By Benezette Williams.

(Journal of the Association of Engineering Societies, New York, vol. iv., 1885, p. 175.)

Hyde Park, a "village" under the laws of the State of Illinois, has an area of about 48 square miles, and is 12½ miles in length from north to south. It comprises three lakes having a combined surface of about 5½ square miles, which are connected with Lake Michigan by the Calumet River, flowing for a total length of 12 miles within the village. The lakes are shallow, having an of average depth of from 1 to 6 feet, and the river has a water-shed about 450 square miles. It would appear that the chief peculiarity of the district is its small elevation above the mean level of Lake Michigan. The northern portion of the township, from Thirty-ninth to Fifty-ninth Street, is merely an extension or suburb of Chicago, and is sewered on the combined system, the drains discharging into Lake Michigan, as the ground is sufficiently high for such a system. Southward of Fifty-ninth Street the territory has

been divided into three districts. Pullman district has an area of 7 square miles, and is for the most part so high as to be capable of being drained by gravitation into the lake. Hyde Lake district, comprising about 6½ square miles exclusive of the lakes, is for the most part marshland. The Central district, which includes many flourishing communities, is 22¼ square miles in extent, receives the storm-water of an area of 12 square miles outside its own limits, and has an average elevation above datum of only 6 feet, more than half the district being only 4·2 feet above datum. Indeed, from observations extending over a long series of years, it appears that for thirty years Lake Michigan has had an average height of only 4·1 feet lower than the average of this district; that its greatest recorded yearly average has been but 3 feet lower; its greatest monthly average but 2·2 feet lower, and its greatest daily average but 1·3 feet lower than the district. The Author states that, except the entire area were artificially raised, as has been done at Chicago, it is impossible to drain the district by natural means. The amount of such filling would, however, be five times as great as in the case of Chicago; and, from the figures which are given for the cost of pumping under the present system in the latter place, it is shown that, to lift the whole of the sewage and storm-water in Chicago, would not have been much, if at all, more expensive than the plan that has been adopted for Hyde Park.

For the storm-water drainage, it is proposed ultimately to conduct the water to the two sites chosen for the pumping-stations; the rainfall and the sewage-water will be kept separate, and both will be pumped. The storm-water will be discharged from the one station into an open drainage-ditch, emptying into Lake Calumet, and from the other into the River Calumet, which flows into Lake Michigan. The sewage-water from both pumping-stations will be distributed over land for the purpose of purification. In order to determine a safe basis for fixing the capacity of the drains, the Signal Service records of rainfall in Chicago have been consulted, and a Table for the twelve years ending in 1883 is given—the average annual rainfall for that period being 37·40 inches. From these, and other considerations, it was decided to recommend that the mains be proportioned to carry $\frac{1}{12}$ of an inch, and the laterals ⅛ inch of rainfall per hour. The apparent difference in capacity between such a system as this, and one designed for a rainfall of ½ inch per hour, is as 1 to 6, but the disparity is really not nearly so great. The calculations used in designing the sewerage-systems were as follows: Assuming that for each 25 feet of street-frontage there are five persons, and that the maximum rate of water used is 120 gallons per head in twenty-four hours, or 5 gallons per hour, then in a mile of street there will be about 10,000 gallons, or say 1,333 cubic feet of sewage per hour. With allowance for sub-soil water, and for a small proportion of the rainfall, it is estimated that the total flow will be 2,000 cubic feet per hour per mile of street. As the land is generally

subdivided in Hyde Park, there are sixteen miles of street upon which frontage should be counted per square mile, or 32,000 cubic feet of sewage per hour per square mile, or 50 cubic feet per acre. It is pointed out that many difficulties will arise in the construction of the sewers and drainage for surface-water in such level territory, and some of the work will be at such a depth that it will be necessary to have recourse to tunnelling. The sewers and surface-water drains will for the most part be on the same lines, and it is proposed to construct them the one above the other; cross-sections of each are given in the Paper, together with a detail plan of the district. The total amount of storm-water to be pumped at each station will equal 40,000 cubic feet per minute; the amount of lift, when but little water is flowing, will be about 25 feet. In storms that tax the capacity of the mains and pumps, the water will rise to within 8 feet of datum, and as it will be seldom that the water will have to be lifted to a greater height than 4 feet above datum, it is safe to take the lift during heavy storms at about 12 feet. Assuming that after allowance for evaporation, &c., 25 inches, or two-thirds of the rainfall of the entire district, have to be carried off by the drains, there will be 1,292,000,000 of cubic feet annually to be lifted to an average height of 15 feet, equivalent to the performance of about 37,000,000 of HP.

In consequence of the many uncertain factors entering into the problem—the risk of encountering quicksands, &c., it is impossible to give the ultimate cost of the scheme. All that can be done is to indicate the relative cost of the proposed plan, as compared with some alternative system which would be practicable under ordinary conditions.

In the Hyde Park territory there are, as a rule, 24 miles of streets for each square mile of surface, 16 miles running north and south, and 8 miles running east and west. To drain this district on the combined system, as practised in Chicago, there would be sewers in every street running north and south, and in every alternate street running east and west, or 20 miles of sewers per square mile. For the separate system as proposed, there will be 8 miles of storm-water drains east and west, and 1 mile north and south, equal to 9 miles per square mile of territory; and for the sewage there will be 16½ miles north and south, and about 1½ mile east and west; a total of about 18 miles per superficial mile.

From a number of American cities, the cost of sewering which, on the combined system, is given, it appears that it varies from $34,550 per mile in Providence, to $15,458 in Chicago; while a separate system ranged from $10,000 a mile in Leavenworth, to $6,875 in Memphis. From various considerations which are indicated, it is fair to assume that the cost of a combined scheme would be 20 per cent. greater here than in Chicago, or say, $18,500 per mile. This would make the total cost per square mile of that system $370,000; making due allowances for running sand, and

difficulties in construction, it is reasonable to assume that the cost per mile on the double system would be as follows:—

	$
Nine miles of storm-water drains at $14,000 . .	126,000
Eighteen miles of sewers at $11,000	198,000
Total	324,000

A saving of $46,000 per square mile as compared with the combined system, and a total saving of upwards of $1,023,500 on the $22\frac{1}{4}$ square miles of territory to be dealt with. This, it is stated, will nearly pay the cost of the two pumping-stations, and the engineers are confident that the double system they propose will not cost materially more than a single combined system discharging by gravitation. In conclusion, many facts are given as to the relative death-rate of towns sewered upon each principle, and the arguments for and against each plan on sanitary grounds are discussed. The Author states that he believes the axiom cannot be gainsaid that, "with the conditions of ordinary practice, if a given amount of sewage, and a given amount of storm-water have to be conducted along a particular street, through underground channels, it can be done cheaper in one channel than in two."

G. R. R.

The Liernur System in Amsterdam.

By Dr. R. Blasius, of Brunswick.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xvii., 1885, p. 237.)

The Author describes a visit paid to that part of the city of Amsterdam drained in accordance with the Liernur system, comprising three thousand one hundred houses with fifty thousand inhabitants. The method of collecting the sewage of a district, by means of exhausting the air in a closed reservoir and conveying the sewage subsequently to the central station is explained, the time actually occupied in gathering the sewage from about fifty houses with one thousand inmates was from seven to eight minutes, in which total is also included its transmission to the central station, several kilometres distant. The central station, only quite recently opened (in August, 1884), was also inspected. It consists of a large hall with several boilers, engines and two air-pumps, which work alternately. Above the collecting-reservoirs, which are in duplicate, are two others situated on an upper floor, into which the sewage is lifted by the air-pumps. In these receivers the mass is stirred by machinery and mixed with from 1 to $1\frac{1}{4}$ per cent. of its volume of sulphuric acid. The contents are then introduced into the steam-concentrator, heated to about 100° Centigrade and brought to the consistency of syrup. It was at first intended to evaporate the mass to a dry powder, by means of

copper cylinders heated by steam, but this was prohibited by a municipal decree, dated December 31st, 1879, and it has consequently been necessary to sell as large a quantity of the liquid manure as possible to agriculturalists. The sale in this form is at present relatively small, and the bulk of the excreta is transported in iron barges to an outlying suburb where it is mixed with ashes and converted into a semi-dry manure. The boat-loads as they arrive are emptied into a large stone-built reservoir, the contents of which are run on to beds of prepared cinders, from 20 to 25 paces square, and from 1 to 1½ metre in depth. The exhalation from these manure heaps must be very offensive in hot weather.

The cost of treatment as set forth in a Paper by the municipal engineer, Mr. C. M. van Bruyn-Kops, is as follows:—Working-expenses the system per head, including interest on the cost of construction, 70 centimes (6·72*d.*). This, however, is taken on a very populous district, inhabited by five hundred persons per hectare (202·4 per acre); if the cost is calculated over the average population of three hundred persons per hectare, the expense must be relatively increased, as 3 : 5, or at the rate of 1·17 francs per head (11·23*d.*). To this must be added the expense of evaporating the excreta which, taken at per head per annum, may be thus stated:—

	Francs.
To evaporate 1,750 litres of water requires 110 kilograms of coal	2·20
6½ kilograms of sulphuric acid at 10 francs per 100 kilograms .	0·65
Cost of labour	0·50
Interest on capital outlay on evaporating works	0·40
Maintenance and renewal of the apparatus	0·80
Miscellaneous expenses	0·25
Working-expenses	1·17
	5·97

Say 6 francs (4*s.* 10*d.*) per head per annum.

From the experience of the Dordrecht works the poudrette contains 7½ to 8 per cent. of nitrogen, and 2½ to 3 per cent. of phosphoric-acid, and has a minimum value of 16 francs per 100 kilos (£6 8*s.* per ton). It may be assumed that each person yields 50 kilograms of poudrette per annum. Thus the value of the produce is 8, the expense 6, the net receipts being 2 francs per head (1*s.* 7·2*d.*).

As in all other systems, that of Liernur entails occasional stoppages in the sewers. For the year 1882, on a population of forty-six thousand three hundred and sixty-two persons, there were in the house connections eight hundred and twenty-five stoppages, in the sewers twenty-eight. The cost of removing the obstructions was 534·29 francs or 2½ centimes (0·25*d.*) per head per annum. The Author sums up the advantages of the system, and investigates the cost as compared with similar processes in England.

G. R. R.

The Utilization of Peat-Fibre. By Dr. R. Blasius.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xvii., 1885, p. 159.)

The employment of peat for sanitary purposes has so greatly increased in recent years that a treatise on its preparation and uses, more especially with a view to the preservation of cleanliness in the soil of towns, is very desirable. Formerly employed almost entirely as fuel, the denser and deeper situated layers were alone of value, and the upper portion of the peat bogs, the so-called "peat-moss" was of so little use that it was collected in heaps and burned on the spot, giving rise to the well-known "moor-smoke," over an area of many miles. Recently, owing to its employment for litter for cattle, and in stables, the peat-moss has attracted more attention. The Author states that, as it will absorb about eight times its weight of liquid, and has, besides this, great affinity for ammonia and other gases, evolved by human excreta, its use as a deodoriser is highly desirable.

An account is given of the method of preparing the fibre. The mossy-peat is first dried, torn into pieces about the size of walnuts by machinery, and is then sifted, during which process the bright brown fibre is separated from a fine brownish powdery mass, termed peat-mould. Experiments have been conducted with this mould, at the Brunswick Polytechnic, to ascertain its efficacy as a deodoriser and absorbent. It has been found by the Author that the carbonic acid in the surrounding soil sank after seven months' trial in a cess-pit from 3·1 parts per mille to 1·1, or to about one-third of the former volume. The approximate cost of the peat-mould in N.W. Germany is given at 1·50 marks per centner (1*s.* 6*d.* per cwt.) and the value of the resultant 8 cwts. of manure after use at 2·80 marks (2*s.* 9½*d.*). The possibility of employing peat-mould for the defecation of towns is also considered by the Author, and the necessity of actual experiment on a comprehensive scale is advocated.

G. R. R.

The Dry-Rot Fungus (Merulius Lacrymans). By Professor Dr. Poleck.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xvii., 1885, p. 105.)

The spread of this fungus during the past decade has been most remarkable throughout Germany, more especially in newly built houses. The causes for its presence and the means of preventing it furnish a most necessary subject for investigation, both on economical and sanitary grounds. This fungus attacks chiefly the coniferous woods; it is never found on living trees, it extends in long delicate threads over the timber and masonry, and occasionally covers them with a fan-like growth. It penetrates

the interior of the wood; its fibres enter the cells and sap-vessels and induce certain chemical changes, by which the timber is converted into a light brittle substance. It feeds on the wood in much the same way that all parasites maintain themselves from the juices of their prey. It subsequently extracts from the timber the mineral constituents by a somewhat obscure chemical process, by which means the structure is eaten away, and further decomposition is effected. The richer a wood is in phosphoric-acid and potash compounds, the more rapid is the growth of the fungus. As wood felled with the sap in it is five times as rich in potash, and has eight times as much phosphoric-acid as timber felled in the winter, it follows that the employment of the former for building purposes is most fatal, if the wood is liable to be attacked by the fungus spores. For various reasons timber full of sap comes in considerable quantities into Germany, and hence arises one cause for the rapid extension of dry-rot, which has reached the dimensions of a public calamity. No plan of prevention appears so successful as thorough ventilation, the free access of warm air, and complete dryness. Further experiments are required to substantiate the utility of the much vaunted chemical antidotes. The presence of the fungus in houses was stated in the course of discussion to be productive of injury to the health of the inmates.

G. R. R.

Heating and Ventilation of the École Monge, at Paris.

By S. PÉRISSÉ.

(Le Génie Civil, Nov. 29, 1884, p. 72.)

The building consists of a basement, ground-floor, and first and second floors, the highest being used as dormitories.

Two sets of three vertical boilers are placed in the basements. From the boilers horizontal pipes pass along the building, and from these double vertical pipes are carried up to the floors of the dormitories through recesses in the walls. On the ground- and first-floors the external air is admitted into the recesses at floor-level, passes up along and is heated by the pipes, and enters the rooms near the ceilings.

The ventilation is obtained by means of two chambers in the roof, which are heated by vessels of hot water, and by the passage through them of the boiler-chimney. In summer they are heated by a small boiler. The ventilating-gratings in the rooms are at the floor-level; the heated air enters at the top of the room, the vitiated passes off at the bottom, and is drawn up to the chamber in the roof and passed out at louvres.

The various departments require different degrees of warming and ventilating; the dining-rooms should be moderately warmed, and not ventilated at all. The pupils do not remain long enough

in them to vitiate the air, and nothing but frequent washing of all the surfaces will remove the smells which cling to them. The class-rooms and dormitories should be warmed (the latter slightly) and thoroughly ventilated. The dining-rooms are warmed by the pipes which return the hot water to the boilers on its descent from the upper stories; it passes through a horizontal pipe laid under the floor on each side of the room, and covered with cast-iron plates. The vertical pipes, also, by which the water descends, are carried through recesses in the walls, with openings at top and bottom, so that the air of the room can be passed through them and heated.

The apparatus consists of three parts, 1st, the boilers for producing the heat; 2nd, the general distribution-pipes, which carry the heat to the different parts of the building; 3rd, the apparatus for utilizing the heat. Each of the boilers has an internal fire-box, 3 feet in diameter and 12 feet high, the outer casing being 4 feet in diameter and 13 feet high. Each boiler holds 550 gallons of water. The boilers have a casing of firebrick, in which the smoke and heated gases circulate. Either one, two, or three boilers can be used at a time. The two sets of three boilers have in all 1,600 square feet of heating-surface, of which 650 square feet are internal. The general distribution-pipes convey the water from the boilers to the various heating appliances and back again. They are cast-iron, with india-rubber joints. They start from a 14-inch pipe connecting the tops of the boilers, radiate to all parts of the building, and return to a pipe connecting the lower ends of the boilers. There are two sizes, 8-inch and 6-inch. Their total capacity is 2,860 gallons. The principal heating appliances are the vertical pipes before mentioned; these pipes have radiating plates cast on them. Their arrangement for the various rooms is described in detail. For a class-room, 24 feet square and 13 feet high, the heating surface consists of—

	Square Feet.
The cylindric surface of heating-pipes	76
Radiating plates of ,, ,, ...	198
Inner surfaces of the masonry recesses	218
Total heating-surface	492

The temperature of the pipe which conveys the water from the boilers varies from 122° Fahrenheit to 220°; that of the return-pipe from 55° to 127°, generally about 92°.

The cubic contents of the buildings warmed are :—

	Cubic Feet.
Dormitories (heated from 50° to 54°)	267,100
Dining-rooms and passages (55° to 59°) . . .	123,678
Class-rooms, linen closets (57° to 61°) . . .	452,581
Fencing-school, lavatories (59° to 61°). . . .	59,931
Parlours, offices, and bath-rooms (61° to 64°) .	92,423
Total	995,713

There are about 86,000 square feet of surface in walls, of which about 26,000 square feet are glazed, and a large proportion are external walls, so that the cooling effect is considerable. With the external temperature varying from − 10° Fahrenheit to − 5°, the internal varies in different parts of the building from 50° to 59°.

Consumption of Coal.—In the winter of 1878–9 (the cubic content of the building at that time being 824,218 cube feet) heating was carried on for two hundred and twenty-six days, and the consumption of Charleroi coal, of the best quality, was 154 tons, including the summer firing, for which cinders were used. In 1879–80 the winter heating lasted two hundred and six days, and the coal used was 116 tons. The difference was due partly to the method of working, partly to the atmospheric temperature. During the former season the mean temperatures for the two hundred and twenty-six days was 42°; during the two hundred and six days of the latter it was 40°. The mean temperature in the school was 58°. The consumption per annum for each 1,000 cubic feet raised from a mean of 42° to a mean of 62½° is 0·187 ton.

General Remarks.—Cast-iron should never be used for heating purposes in such a way that it will become red hot, as it develops oxide of carbon, a very poisonous gas. This action does not take place to so great an extent when the air is moist. The desideratum in heating is to keep the body at a suitable temperature, the greatest heat being at the feet, and a fresh pure air, without draught, at the head. This is best obtained by radiation, as from the rays of the sun on a cold bright day. To carry out this idea, radiating bodies should be placed near the floor, and air should be admitted fresh, or slightly heated, by a system of aspiration or impulse, independent of the heating. The system at the École Monge does not attempt to carry out this principle, as hot air is the agent employed for warming the rooms. This air is, however, much purer than in many similar installations, as it is admitted direct to the recesses which contain the heating-pipes from the fresh air outside the rooms. The Author considers that the system of ventilating from below upwards in the rooms is in some respects superior to that from above downwards. The former is natural, the latter artificial, and depends upon all the parts of the system being worked efficiently. On the whole, however, the system answers its purpose, but is better adapted for climates in which changes of temperature do not occur suddenly, as from the fact of there being in circulation 1,500 cubic feet of water, the degree of heating cannot be rapidly altered. The system is healthful and works economically, but the first cost was higher than it would have been on the hot-air principle, the whole installation having cost £4,000.

W. H. T.

The New Draining-Engines at Gréasque, France. By V. Grand.

(Gazette de Travaux Publics, 12 Oct. 1884.)

The system of draining by hydraulic engines erected by Messrs. Hathorn, Davey & Co., is composed of the following parts:—

1st. In a chamber C, excavated close to the "Lhuillier" pit, and near the water to be raised, are placed two hydraulic engines, working directly two double-acting pumps which force the water to E into the drain-gallery of the valley of the Arc. (Later it is intended to deepen the pit as far as A, and to erect in B an analogous system to that which is already placed in C). Each hydraulic engine is composed of a plunger working in two cylinders placed one in front of the other. This plunger carries both before and behind a rod; that behind serves only as a guide, whereas the other is coupled to the plunger of the pump. Each cylinder carries two stuffing-boxes, one for the plunger, the other for the rod; above each cylinder is a distribution-box in communication with the conduit of motive-water.

The distribution is effected by means of a hollow cylindrical valve in which moves a double-beat valve; the whole is worked by the water under pressure, as in most of the non-rotative engines worked by a column of water. The distribution is reversed by a reversible slide-valve, which is displaced at the end of each pump's stroke by a rod furnished with tappets, which are struck by a cross-head guide following the motion of the pump plungers.

The pump attached to each hydraulic engine is double-acting; like the engine, it is composed of two cylinders placed one in front of the other; it has only one rod, which is coupled to that of the plunger of the engine. Each pump-barrel has a stuffing-box for the plunger; that situated nearest the engine has a second stuffing-box for the plunger-rod; at the extreme end of each of these pump-barrels are placed suction- and delivery-valve boxes.

The delivery-pipes of both pumps are joined to a single rising-main, which empties the water in E.

2nd. In F, at the surface, is the prime mover which is to furnish the water-power for the two hydraulic engines; it consists of a compound rotative condensing-engine of considerable expansion. The two pistons of this engine are coupled with cranks fastened at right angles, a suitable fly-wheel is keyed on the main shaft between the two cylinders. The piston-rod of each cylinder extends through the bottom of the same, so as to work a double-acting plunger-pump, called a compression-pump; this pump forces the water into a steam-accumulator which is composed: (1) of a pump-barrel of small diameter in communication with the compression-pumps of the steam-engine on the one side, and with the column of power-water on the other, the said column ending in the hydraulic engines placed in C; (2) of a steam-cylinder of large diameter, into the further extremity of which is carried a

steam-pipe. The pump-barrel and cylinder are rendered firm by means of strong iron bars bolted down; (3) of two pistons united to the same rod, and circulating respectively in the pump-barrel and in the steam cylinder. The pump has a plunger constantly submitted to the pressure of the pressure-water, the flow of which it regulates in the column of motive water. The piston of the steam-cylinder is an ordinary metal piston, the face opposite the rod receives constantly the steam-pressure from the boilers; the difference between the surfaces of the steam-piston and the plunger gives regularly to the water forced into the accumulator a pressure of 42 atmospheres.

That part of the steam-cylinder comprised between the piston and the cover is in constant communication with the atmosphere by a tube of small diameter, the hole of which is at a certain distance from the cylinder cover. In case of a rupture of the conduit-pipe of the motive-water, the piston of the accumulator would go beyond this hole, and at that moment, the imprisoned air acting as a cushion, would suppress shocks, while the rod of the accumulator would stop the engine by means of a tappet.

In case of the water rising in the pit much above the point C, the steam-pressure in the accumulator should be proportionately diminished, for which purpose a valve for reducing the pressure is supplied.

The following are, briefly, the advantages of this system of draining:—

1. All the underground pumps have plungers.
2. Continual motion of the water in all the pipes, and therefore diminution of shocks and of sudden losses of power.
3. A steam regulating-accumulator, avoiding shocks at the surface, and preventing accidents. The accumulator plays an altogether different part from the dead-weight accumulator; this one serves principally to store up power, but, considering its great mass, it presents but little elasticity; the other, on the contrary, presenting a very feeble inertia, its oscillations can follow the varying linear speeds of the pumps of a rotative engine, which explains the high efficiency announced by Mr. Davey.
4. Economy of steam, resulting from the whole of the arrangements, which have been successively perfected during a practice of fifteen years, and which gives an efficiency of 33,000 lbs. raised one foot high, for less than 14 kilograms of steam per hour.

The "Société Anonyme de Charbonnages des Bouches-du-Rhone" believes that this system will supersede all those which have been employed in France until the present day, especially in cases where it would be impossible to make use of engines of the type commonly known as Cornish pumping-engines.

H. D.

Trials made with a Corliss Engine at Creusot Works.

By F. Delafond.

(Annales des Mines, vol. vi., 1884, p. 197.)

The trials extended over a period of six months during part of the year 1883, and principally had for their object the elucidation of the following important points:—

The relation that exists between the I.HP. and that given off from the crank-shaft.

The effect of variation of steam-pressure, rates of expansion, condensing and non-condensing on the consumption of steam; also the influence of compression, piston-speed and steam-jacket. Experiments were also made when the jacket was supplied with a higher pressure of steam than that used in the cylinder.

The engine experimented on was a Corliss horizontal, having a single cylinder $21\frac{5}{8}$ inches diameter by 3 feet $7\frac{1}{4}$ inches stroke, the clearances at each end being about 3·66 per cent. of the piston-sweep. Only the barrel of the cylinder was steam-jacketed, the heads being clothed to prevent radiation. On the trials the engine was supplied by steam from a special boiler, the feed being measured in a tank, and at the close of each experiment the boiler was fed up to the same level as when the engine started. In order to prevent any error creeping into the measurement of feed-water through the oscillation of the water-level in the special boiler, the engine was worked with steam from the ordinary boiler, until a trial was ready to commence; then the valve was shut on the steam-main leading from the ordinary boiler, and the steam-main opened to the engine from the special boiler. The duration of each trial was from twenty to one hundred and twenty minutes.

The injection-water was measured through a Kennedy meter, and by noting the difference in temperature between it and the air-pump discharge, the rejected heat was ascertained, and the amount of priming-water contained in the steam calculated, but it was found that owing to the uncertainty that existed with several of the observations, the results obtained were not to be thoroughly relied on.

The power of the engine was absorbed by a friction-brake, which was keyed directly on to the crank-shaft, and a special set of thirty-three experiments was made when the condenser was in use, and thirteen without; the I.HP. varying in the first case from 16 to 209, and in the latter from 11 to 195, the speed remaining almost constant through the series at sixty revolutions per minute.

The relation that existed between the brake and the I.HP. may be expressed by the following equations:—

Condenser in use . . B.HP. = 0·902 I.HP. – 16
Working non-condenser B.HP. = 0·945 I.HP. – 12

Several series of trials were made to ascertain the amount of steam used; the most important ones were—

When condensing and the jacket at work with boiler-pressures of 110, 90, 64, 50, and 35 lbs. on the square inch.

When condensing and the jacket shut with similar boiler-pressures.

When non-condensing and the jacket at work with boiler-pressures of 110, 78, and 50 lbs.

When non-condensing and the jacket shut with similar boiler-pressures.

The speed on all the above trials remaining almost constant at sixty revolutions.

In all cases, for each boiler-pressure, several trials were made at different rates of cut-off.

The general deductions drawn were as follows:—

That the best result is obtained with the moderate steam-pressure of 64 lbs. and about five expansions, when 17·32 lbs. and 21·23 lbs. of steam are used respectively per I.HP and per B.HP. per hour. The power given out being from 120 to 170 HP., with powers above and below those limits the steam-consumption was greater. A steam-jacket is more beneficial as the boiler-pressure and the rates of expansion are increased, but it is of little value for light pressures and a very late cut-off. Compression is of advantage, and especially so when the engine is working without the condenser. The initial condensation increases with the boiler-pressure and the rate of expansion, but it is reduced by jacketing, and advantage was found by increasing the temperature of steam in the jacket, and also by increasing the piston-speed.

Tables are given with the results of the various trials, and in addition they are combined and graphically plotted.

J. G. M.

The Dessau-Cottbus Drying Machine. By Mr. Lévy.

(Bulletin de la Société Industrielle de Mulhouse, 1884, p. 406.)

This machine for drying piece-goods appears to be an improvement on Welter's drying-machine, which has already been noticed.[1] The drying-chamber may be varied in width. It is furnished with drums or rollers for moving the cloth by an endless chain; and the current of heated air is drawn in and expelled by means of ventilating fans.

The drying-chamber, which, with the apparatus for introducing the cloth, and the folding-apparatus for receiving it from the chamber, forms the machine properly so-called, is about 33 feet in length, and 10 feet in height. The width is regulated according to that of the cloth to be dried, and is a little wider than the

[1] Minutes of Proceedings Inst. C.E., vol. lxxv., p. 373.

cloth. At each end of the chamber the cloth passes over one of the drums, which are telescopic and adjustable to the width of the cloth. The chain is of malleable cast-iron, in short links 3 inches long between centres, connected by slot-pins. All gearing is external to the chamber, and is easily examined. There are four drums, one over another, at each end of the chamber, over which the cloth traverses the chamber eight times. The chamber is subdivided by four horizontal partitions of sheet-iron, by which the current of hot air is conducted so as to traverse the whole of the chamber alongside of and in contact with the cloth. The chamber is fitted with doors and windows for inspection.

The cloth to be dried is fixed by the edges to the chains, which are fitted with points to seize and hold the cloth. It enters at the uppermost part of the chamber, and leaves at the bottom, at the same end as that through which it enters, and is folded automatically as it arrives. The speed of the traverse is regulated by means of cone-pulleys.

The function of the ventilating-fans, of which there are two, is to extract and discharge outside the humid air from the chamber at the top, and consequently to draw in fresh heated air at the bottom. Two currents of air traversing each one of the faces of the cloth are produced, moving in a direction contrary to that of the cloth, which traverses the chamber from top to bottom. Thus the dampest parts of the cloth come into contact with the warm air loaded with moisture, and about to be extracted, whilst at the lower part the portions of cloth which are nearly dry come into contact with hot air carrying very little humidity. The fans are 31½ inches in diameter, and make from 700 to 800 turns per minute.

The air is heated in two chambers underneath the drying-chamber, containing two groups of cast-iron pipes in four tiers, one to each chamber, formed with flanges or transverse ribs on the outside for the purpose of augmenting the heating-surface. External air is admitted into the heating-chambers, whence it issues, after having been heated, through two openings 38 inches long by 8 inches wide, into the drying-chamber, and upon the two faces of the cloth.

A Dessau-Cottbus drying-apparatus, working at the factory of Messrs. Schaeffer, Lalance & Co., at Pfastatt, has been tested for performance. Each heating-pipe has a normal surface of 2¾ square feet, which is increased by flange-surface to nearly 11 square feet, making a total heating-surface of 1,550 square feet. The indicator-power of the steam-engine by which the apparatus was driven was as follows:—

	Turns per Minute.	I.HP.
Engine and driving-gearing only	98·7	5·44
" " and ventilators.	96·8	9·25
" " " and drying-chamber	99·22	10·97

From this it appears that the ventilators absorbed 3·81 I.HP., and the drying-chamber 1·72 I.HP.; together, 5·53 I.HP.

The average results of three days' tests show that the temperature of the external air was 64·5° Fahrenheit; at the entrance to the heating-chamber, 70°; at the exit of the chamber, 170°; within the chamber, near the windows, 146½° above, and 77° below; on leaving the first ventilator, 88°; and the second ventilator, 95½°. There was 0·90 inch of vacuum in the chamber; the air entered the first fan at a speed of 65 feet per second, making a delivery of 99½ cubic feet per second, and the second fan at a speed of 58 feet per second, making 89 cubic feet per second. The corresponding quantity of air entering the heating-chamber per second was only 42 cubic feet, showing that considerable leakage into the drying-chamber must have taken place. The average absolute pressure of the steam in the pipes was about 24 lbs. per square inch, and 3,385 lbs. of steam was consumed in nine and a half hours, the duration of the test. The quantity of cloth dried was 68·2 pieces, 5,760 yards in total length. The gross weight before drying was 2,776 lbs., of which 1,222 lbs. of water, or 44 per cent., was evaporated. The steam consumed to evaporate 1 lb. of moisture, exclusive of engine-power, was 2·773 lbs.; and the steam condensed per square foot of heating-surface of pipes per hour in active work, 2·48 lbs.

The efficiency of the ventilators, and that of the heating-apparatus and the drying-chamber, are discussed at length in the Paper; also the cost of the apparatus, the total of which is stated as £1,280.

D. K. C.

Friction of Lubricating Oils (Second Paper).

By C. J. H. Woodbury.

(Transactions of the American Society of Mechanical Engineers, vol. vi., 1884.)

This Paper is an extension of the Paper on the same subject previously read by the Author.[1] In the present Paper, the Author directs his attention to the examination of a single lubricant under various pressures and various temperatures. A standard brand of mineral oil, of uniform quality, free from admixture of any animal oil, was selected for the purpose. It showed—

Flash	342° Fahr.
Fire	410° „
Evaporation by exposure to a temperature of 140° Fahr. for twelve hours	0·02
Specific gravity	0·888

The action of the testing-machine is based on the principle of measuring the friction between two annular disks, scraped to offer true plane-surfaces in contact. The upper disk has the form of a

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[1] Minutes of Proceedings Inst. C.E., vol. lxv., p. 428.

hollow ring, based on a flat plate. Water can be introduced into it to control the temperature of the disks, and in some instances it is desired to use the water as a medium to retain the heat of friction. The sides and top of the upper disk are cased in hard rubber, and the interspace is filled with eider-down. In experimenting, ice-water is used to reduce the temperature nearly to the freezing-point; and the friction is noted at each degree of the rise in temperature due to the heat of friction.

Three large tables of results of experiment are given, with diagrams showing the resistance of friction of a paraffine oil tested in the machine at pressures of from 1 lb. to 4 lbs. per square inch, and temperatures ranging from 40° Fahrenheit to 100° Fahrenheit. As the temperature rises, the increasing fluidity of the oil leads to a diminution of the friction within the limits of free lubrication. It is also seen that the resistance does not increase proportionately to the pressure, nor at a uniform rate. The following are selections of coefficients of friction at the velocity 300 feet per minute. For the temperatures—

40° 50° 60° 70° 80° 90° 100° Fahr.,

the coefficients of friction are, for the following pressures per square inch—

1 lb.	0·54	0·43	0·34	0·27	0·21	0·17	0·14
2 lbs.	0·30	0·23	0·19	0·15	0·12	0·10	0·08
4 „	0·17	0·13	0·11	0·09	0·07	0·06	0·05
8 „	0·10	0·08	0·06	0·05	0·05	0·04	0·03
16 „	0·06	0·05	0·04	0·04	0·03	0·03	0·24
32 „	0·04	0·034	0·03	0·026	0·024	0·022	0·02
40 „	0·035	0·03	0·027	0·024	0·02	0·02	0·02

The diminishing coefficients relatively to rising temperature are due to the diminishing viscosity of oil with the rise of temperature. The coefficients diminishing with the increased pressures are due to the thinning of the film of oil between the surfaces, as the pressure is increased.

Considerations of safety have fixed the minimum limit of the flashing point of a lubricating oil at 300° Fahrenheit, with a proportion of volatile matter not exceeding 5 per cent. thrown off by exposure to the temperature 140° Fahrenheit for twelve consecutive hours. In some places, it has been found that though, by the use of an extremely thin oil, a diminution of friction was effected, the journals were more rapidly worn.

In conclusion, the Author points out that, "the problem of lubrication seeks to know what combination of oil-casks, coal-pile, and wear-and-tear will represent the fewest dollars."

D. K. C.

On Retarded Ebullition and Superheated Water.
By H. WALTHER-MEUNIER.

(Bulletin de la Société Industrielle de Mulhouse, 1885, p. 113.)

The Author, in response to numerous inquiries, has studied the question of the possibility of boiler-explosions caused by the superheating of water in the boiler; that is, the heating of water to a temperature higher than that due to the pressure. He notices the results of various laboratory experiments on the subject, which lead to the following conclusions:—That the state of absolute repose is indispensable for the production of the phenomenon of superheat of water; and that the presence of air or other gas, even in indefinitely small proportions, maintains ebullition under normal conditions. He finds from the official statistics of boiler explosions for six years 1877–82, in England, France, and Germany, that the proportion of explosions from unknown causes were eight in one hundred and fifty for England, thirteen in one hundred and fourteen for France, and three in one hundred for Germany. These average about 6½ per cent. But, on closer examination, the proportion of totally unknown causes for France is reduced to 3 per cent. For Germany, there is no cause classed as totally unknown; and for England, only 1 per cent.: making a total average of 1·1 per cent. of totally unknown causes. This percentage is easily explained, in face of the difficult and laborious work of investigation after an accident, without needing to ascribe its origin to the existence of superheated water.

The Author maintains that, in a steam-boiler, whether at work or at rest, there is continual agitation and circulation arising from differences of temperature; and that superheating of water in the boiler is impossible. Besides, the presence of the smallest quantity of air is sufficient to impede or prevent superheating of water—a condition which is always fulfilled in practice, and which is clearly confirmed by the fact noticed by the Author, that, at the temperature of discharge of condensing water, 86° Fahrenheit, the tension of the vapour is 0·041 atmosphere, whilst there is never less than 0·12 atmosphere of back pressure, making the difference, 0·079 atmosphere, which is only explained by the pressure of air. After a consideration of the conditions of boilers of different types, the Author concludes that all boiler explosions may be explained by bad materials, bad construction, bad design, or want of care and precaution.

D. K. C.

Distribution of Power by Rarefied Air. By LOUIS BOUDENOOT.

(Comptes rendus de la Société des Ingénieurs-civils, 1885, p. 143.)

The utility and necessity of supplying power, cheaply and conveniently, in small quantities, for domestic service, in large towns,

is generally admitted. Mr. A. L. Petit, in 1874, proposed the distribution of motive power in private houses by means of rarefied air; and in 1881 his views were carried into practice on a small scale. Mr. Boudenoot passes in review the different systems of producing or transmitting force in small quantities: by steam, as in New York; by water-pressure, electricity, and coal-gas. Comparing compressed air and rarefied air, he notices the high first cost for apparatus, and of production of compressed-air, and the low efficiency—21 per cent.—against an efficiency of 45 per cent. for rarefied air.

In the establishment in the Rue Beaubourg, Paris, a vacuum of 75 per cent. is maintained, by means of pneumatic machines, in a system of piping in connection with the apartments supplied with power, where it may be connected to the domestic motor. Motion is thus derived by the pressure of the external air; and the consumption of power is determined by a meter. The exhausting-engine is of 70 HP., having one cylinder, horizontal, and connected direct to the exhausting-cylinder, by which air is extracted from the vacuum-pipes. The engine makes sixty revolutions per minute; the air-cylinder cutting off rarefied air at one-fourth, and expelling it at atmospheric pressure. The air-cylinder is prevented from heating by cold water injected into it. It is 40 inches in diameter, with a stroke of about 40 inches, calculated for the distribution of from 35 to 40 HP. to houses. The system of vacuum-pipes is laid in the sewers. The pipes vary from 10 inches in diameter near the central establishment, to 8 inches, and thence to 6 inches. The branch-, or service-pipes are of lead. The total loss of head is not more than 3 or 4 per cent. The motors adopted are: the oscillating motor, the rotative motor, and the *moteur à fourreau*. The pipes are exhausted of air so as to cause a vacuum during eight hours a-day; occasionally, twelve hours in the day. Motors of 1 HP., $\frac{1}{2}$ HP., or $\frac{1}{3}$ HP., would conveniently drive a dynamo-electro machine for from three to six or ten lamps. The company supply power for driving lathes for various purposes, rolls, drills, planing-machines, sewing-machines, circular saws, band-saws, ventilators, and many other machines. The charge for power for working a sewing-machine amounts to $8\frac{1}{2}d.$ per day of ten hours.

D. K. C.

On Explosive Gaseous Mixtures.

By Messrs. Berthelot and Vieille.

(Annales de Chimie et de Physique, 6th series, vol. iv., 1885, pp. 13–90.)

These experiments were made to determine the pressure developed and the heat generated by the explosion of various gaseous mixtures in closed vessels. Tables of results are given, and from them the Authors deduce the limits of temperatures of

combustion, dissociation, and the specific heats of the gases at very high temperatures. The results, methods of experiment and calculation, are discussed in eight Papers.

1*st*. *On the calculation of the Temperatures of Combustion, the Specific Heats and Dissociation of Explosive Mixtures.*—This Paper is the continuation of a memoir by Mr. Berthelot in 1877, and contains a theoretical consideration of the principles which have guided the Authors in these investigations.

Given the pressure P developed by the explosion of a gaseous mixture, the temperature of combustion is determined by the method of limits. In the case of no dissociation, a limit above or equal to the real temperature of combustion is given by the formula

$$t_1 = 273\left(\frac{P}{H}\frac{1}{g} - 1\right),$$

where H is the initial pressure at 0°, and g is the ratio of the volume occupied by the burnt products completely combined to that of the same bodies entirely dissociated. If the initial temperature be above zero, say T, then $P\left(1 + \frac{T}{273}\right)$ is used instead of P in this formula, which is deduced from the laws of Mariotte and Gay-Lussac. When there is complete dissociation and none of the products really combined, another limit t_2, below the temperature of combustion, is found from the equation

$$t_2 = 273\left(\frac{P}{H} - 1\right).$$

The real temperature of combustion lies between these limits t_1 and t_2, which are brought much closer by the presence in the mixture of inert gases, such as nitrogen—in the case of combustion by means of air. Two sorts of systems are considered. Reversible systems where the compounds formed by combustion can, by dissociation, be split up into the original components: such are $C\,O_2$ forming $C\,O$ and O, and water-vapour giving H and O. In non-reversible systems, dissociation does not produce the original components. Thus a mixture of cyanogen and oxygen, on complete combustion, yields $C\,O_2$ and N, whilst dissociation tends to produce O and $C\,O$ or even free carbon. Knowing Q the quantity of heat generated by complete combustion at constant volume, another limit t_4, intermediate between the preceding ones, is calculated for reversible and a few non-reversible systems. The mean of t_1 and t_4 gives a close approximation to T the temperature of combustion.

Then the total heat Q divided by the values t_1, t_2, t_4, T, gives a set of corresponding limiting values c_1, c_2, c_4, C, of the apparent specific heats of the system at constant volume between 0° and T. The apparent specific heat includes the specific heat properly so-called, and the heat given up by the recombination of the dissociated components. The mean value C of c_1 and c_4 represents the specific

heat. This applies to such gases as CO_2 and water-vapour, even when mixed with inert gases—like N or with hydro-carbons. Thus values of the specific heat at constant volume of different systems are deduced for temperatures ranging between 1,700° and 5,000° on the air-thermometer.

When two elementary gases combine at constant volume without condensation, the ratio of the effective temperature t, to the temperature T which would be produced by complete combustion, that is t_1 T, gives the ratio of the volume of the portion really combined to the total volume and hence determines the dissociation.

Special stress is laid on the results obtained from a group of isomeric mixtures, *i.e.*, mixtures which contain the same elements in different states of combination, but all yielding an identical mixture after combustion.

2nd. *Experimental determination of the Pressures developed in Gaseous Explosive Mixtures at the moment of explosion.*—The pressures have been obtained by exploding the gaseous mixtures in spherical vessels, and registering on a revolving cylinder the law of the displacement of a piston of known section and mass. Complete data of two experiments are given with readings taken off the curves at given intervals of time during each experiment. The cooling effect of the walls of the vessels, is observed by exploding the same mixture in vessels of different capacities. The results are fairly concordant with those obtained by Messrs. Bunsen, Mallard and Le Chatelier by entirely different methods, so far as the latter extended. The Authors have made numerous experiments with forty-two different mixtures of H, O, N, C O, CH_4, N O, cyanogen, ether, &c., and the pressures are recorded.

3rd. *Relative Rate of Combustion of different Gaseous Mixtures.*—Three explosion vessels of different capacities and shapes were employed. The maximum pressure observed when a mixture of gases is exploded in a vessel at constant volume is always less than if the system retained all the heat generated by combustion, the loss of heat being due to contact with the walls of the vessel and to radiation. This difference is greater the smaller the explosive-vessel or the smaller the mass of gas with respect to the vessel, and it is also greater the slower the rate of combustion. The time required for the development of the maximum pressure is generally longer the larger the explosive-chamber, and the greater the distance between the piston and the point of ignition. C O is slower than H; but for cyanogen and hydro-carbons rich in H, the time is about the same as for H alone, and agrees with the calculated velocities of the explosive waves. The velocity of translation of the molecules governs the phenomenon. Assuming that the flame reaches the piston at the moment of maximum pressure, the absolute rate of combustion is about 100 metres per second for hydrogen, 8 metres for carbon mon-oxide, and 70 metres for cyanogen. This is diminished by an excess of one of the combustible gases, and even more so by the presence of the burnt

products. An inert gas like N retards combustion not only by lowering the temperature and thus diminishing the velocity of the molecules, but also by preventing contact between the molecules which act on one another. With a mixture of carbonic oxide and hydrogen in oxygen, each gas appears to burn separately at its own rate, the hydrogen burning before the carbon, and consequently the maximum pressure observed does not correspond with a uniform state of combustion of the system.

4th. Influence of the Density of Explosive Gaseous Mixtures on the Pressure.—If, in a gaseous system to which heat is communicated, the pressures vary in the same ratio as the densities, it follows, independently of all hypotheses on the laws of gases: (1) That the specific heat of the system is independent of its density, that is, of the initial pressure, and depends solely on the absolute temperature. (2) That the relative variations of the pressures at constant volume, produced by heat given to the system, is also independent of the pressure and is a function of the temperature alone. In fact the pressure itself varies directly as the absolute temperature, and, according to the theory of perfect gases, serves to determine it.

The Authors overcame the difficulties attending direct measurements at high temperatures by two methods. One consisted in using a vessel, one part of which was maintained at the ordinary temperature in the air and the other heated in an oil bath to about 153°, which reduced the density of the gas about a third. The second and more exact method consisted in experimenting on isomeric mixtures. From numerous experiments with isomeric mixtures, under different conditions as to density and heat generated, the observed results confirm the ordinary laws of gases.

The Authors conclude that for temperatures up to 3,000° or 4,000° on the air-thermometer:—

(1) When a given quantity of heat is communicated to a gaseous system, the variation in the pressure of the system is proportional to its density.

(2) The specific heat of gases is sensibly independent of the density at very high temperatures as well as at zero.

(3) The pressure increases with the quantity of heat given to the system.

(4) The apparent specific heat increases with this quantity of heat.

5th. Temperatures and Specific Heats calculated from the experimental results.—These are calculated, by the methods described in the first Paper, from the pressure P developed during the explosion, and the total quantity of heat Q generated by the complete combustion of the gaseous mixtures. The mixtures are arranged in four groups, and two tables are given for each group, containing the values obtained for the temperatures and specific heats.

6th. Specific Heat of the Elementary Gases at very high temperatures.—The Authors agree with Messrs. Mallard and Le Chatelier in the

general conclusion, that the specific heat of gases increases with the rise of temperature, and that the simple gases have sensibly the same specific heat at all temperatures. By supposing the increase to be proportional to the temperatures between 2,800° and 4,400°, the Authors deduce from their experiments the empirical formula

$$C = 6 \cdot 7 + 0 \cdot 0016\ (t - 2{,}800),$$

which gives the specific molecular heat at constant volume of nitrogen, hydrogen, oxygen and carbonic oxide. Between 0° and 200° the specific molecular heats at constant volume of these gases are about 4·8, and the Authors find this number doubled in passing from 0° to 4,500°, becoming 9·8. The variation takes place at all temperatures; it is inappreciable from 0° to 200°, but increases rapidly at high temperatures. The law of increase of the mean specific heat above 1,600° is expressed by the formula

$$4 \cdot 75 + 0 \cdot 0016\ (t - 1600).$$

The real specific heat at constant volume, *i.e.*, the quantity of heat necessary to change the temperature 1°, is calculated by the formula

$$4 \cdot 75 + 0 \cdot 0032\ (t - 1{,}600)$$

for the elementary gases at temperatures from 1,600° upwards.

The specific molecular heat at constant volume of chlorine is greater than that of the simple gases, being 6·6 between 0° and 200°; also at 1,800° the mean specific heat of hydrogen is 5·1, whilst that of chlorine is 15·3, thus approaching that of carbonic acid, which is about 18.

7th. Specific Heats of Steam and Carbonic Acid at very high temperatures.—The mean specific heat of steam at constant volume deduced by the Authors from their experiments may be expressed by the formula

$$16 \cdot 2 + 0 \cdot 0019\ (t - 2{,}000)$$

where t is from 2,000° to 4,000.° The mean specific heat of steam at constant volume between 130° and 230° being 6·65, it is doubled at 2,000° and trebled at 4,000°. The heat of formation of water continually diminishes as the temperature rises. This is partly due to the heat spent in the work of molecular separation without decomposition, and partly to the heat absorbed in decomposition or dissociation. About 3,000° dissociation would absorb at most 6,600 calories, that is, one-seventh of the heat of combustion, whilst molecular separation would absorb at least 8,600 calories or about one-fifth of the heat of combustion at this temperature. These numbers are given with all reserve.

The mean specific heat of carbonic acid at constant volume between 0° and t is given by the formula

$$19 \cdot 1 + 0 \cdot 0015\ (t - 2{,}000)$$

where t is from 2,000 to 4,300. As in the case of water the results show that the heat of combustion of CO to form CO_2 diminishes with the temperature above 200°. The Authors calculate that about 4,500° the heat of combustion would be 28,000 calories and dissociation would absorb at most 18,000 calories, that is, about two-thirds of the heat, whilst at least 22,000 calories of the heat is absorbed by intra-molecular transformation. Comparing the heat of combustion of H_2O and CO_2 at 0°, they are almost equal, being 58,700 calories and 68,000 calories respectively, whilst at 3,000° they become 26,000 and 38,000. Thus their ratio decreases as the temperature increases, and at very high temperatures the carbon tends to entirely decompose the steam.

8*th. Scales of Temperatures and Molecular Weights.*—The results of the previous Papers are considered. Two air-thermometers are compared, the scale of temperatures of one being determined by the dilatations of volume at constant pressure (or by variations of pressure at constant volume) whilst the scale on the other is determined by the quantities of heat absorbed. At very high temperatures these differ widely from one another, and from similar chlorine—or iodine thermometers, owing to the variations in the specific molecular heats which, especially in the case of chlorine, would point to changes in the ultimate molecular constitution of substances hitherto regarded as elementary.

W. R.

Apparatus for Testing Carbonic Acid and Illuminating-Hydrocarbons in Coal-Gas. By — Chevalet.

(Report of the Transactions of the Société Technique de l'Industrie du Gaz en France in the Journal des Usines à Gaz, Feb.-March 1885.)

At the meeting of the "Societé Technique" in 1882 Mr. Chevalet explained the Orsat Apparatus for determining carbonic acid and carbonic oxide in coal-gas. This apparatus requires careful manipulation, is easily broken, and, if the slightest leaks exist in the taps or joints, it does not give correct results, and therefore can only be used by practised chemists. The apparatus now proposed by Mr. Chevalet determines the carbonic acid and sulphuretted hydrogen at the same time. It consists of a cylinder, similar to those employed for the Referees sulphur tests, with a cock fixed on the lower outlet; a stick of caustic potash of a known weight is fixed upright in the cylinder, the top is closed with a cork having a double-bent tube in it, the further limb being graduated and dipping into a glass vessel filled with water. The cock at the bottom of the cylinder is connected with the gas-supply and gas passed through until all the air is expelled, the cock being then closed. If the gas contains carbonic acid, the water from the vessel will rise in the graduated tube, and the vessel must be raised so that the water-level in it is the same as in the graduated

tube. After 15 to 20 seconds, if the water remains stationary in the graduated tube the absorption is complete, and the quantity of water which has entered the tube can be read off if it is graduated so that each large division represents the one-hundredth part of the contents of the cylinder and connections, when each large division will represent 1 per cent. of carbonic acid absorbed, and minor divisions may be made. To obtain exact results there should be no change of temperature during the experiments, and the cylinder should not be touched with the hands nor be placed near a fire. The tap and the cork must also be perfectly tight. With this apparatus the gas can be tested before and after passing through the purifiers, but for this it is advisable to employ two apparatus so as to take simultaneous tests. Tests made with it at a works where only oxide of iron was used for purifying the gas gave the following results:—

Before the purifiers . . .	2·45	per cent. absorbable gases.
After " . . .	2·25	" "

showing that the oxide of iron arrests very little of those gases.

With certain modifications the apparatus may also be used for estimating the illuminating hydrocarbons in gas. The cylinder used is of a slightly different shape and is fitted with ground-glass stop-cocks in the upper and lower openings; these are necessary because the bromine to be used attacks the cork, india-rubber and brass fittings.

To make a test, the bottom stop-cock is connected by a rubber tube with the gas-supply, the two cocks are opened and gas is allowed to pass through and expel the air and fill the cylinder with gas, the cocks are then closed, first the lower and then the upper one.

The top stop-cock terminates in a tube into which ½ cubic centimetre of bromine is placed from a pipette and diluted up to 5 cubic centimetres with water; the orifice of the tube is then closed with the finger, and the bromine and water allowed to run into the cylinder by opening the cock, which is then closed and the cylinder well shaken to bring the gas in contact with the bromine and water; this absorbs the illuminating hydrocarbons, such as olefiant gas, propylene, butylene, &c., but leaves the marsh gas hydrogen and carbonic oxide unaffected.

After well shaking, 5 cubic centimetres of a concentrated solution of potash is passed into the cylinder by means of the tube of upper cock, and the cylinder again well shaken, until the reddish-yellow vapours of the bromine have completely disappeared. The end of a double-bent tube is then fitted into the tube of the upper cock, the further limb of this tube being enlarged to form a pipette, and divided into 1 or ½ cubic centimetre divisions, the end of the pipette dips into a glass containing water, and, on the upper cock being opened, the water will at once ascend into the pipette, the water vessel must be raised so that its water-level corresponds with that of the pipette, and, when this level ceases to rise, the

quantity of water in the pipette can be read off. Assuming this quantity to have been 13 cubic centimetres, the 5 cubic centimetres, bromine and water, and 5 cubic centimetres potash solution must be added, making a total of 23 cubic centimetres; this divided by the contents of the cylinder and tube, in cubic centimetres, and the quotient multiplied by 100, will give the percentage of gas absorbed by the bromine and potash; and, subtracting from this the percentage of carbonic acid, ascertained by a previous test with potash alone, the quantity of hydrocarbons absorbed by the bromine is finally obtained.

If several successive tests are carefully made, so that no gas is lost during the manipulation, the results will be found to vary very little—not more than 0·002 per cent. The process is therefore accurate, and, above all, easy to manipulate, as it does not require water or mercury vessels nor instruments of precision for measuring the volume of gas experimented with. An essential precaution is to work with a diffused light, away from any source of heat, and, when possible, in a laboratory facing the north, so that the sun's rays may not enter, as they would expand the gas in the cylinder and falsify the results.

C. G.

Ravanelli's Gas-Economizer. By G. A. Reycend.

(L'Ingeneria Civile e le Arti Industriali, 1884, p. 167.)

The apparatus consists in an arrangement for heating the gas on its way to the burner, thus effecting a more complete combustion, and increasing the illuminating power of the flame. The gas-pipe is bent so as to pass over the flame, and is at that point widened out for a short distance to form a heating-chamber, from which the gas passes in an ordinary pipe to the burner. In this way the proper degree of heat is obtained, and the danger of partially decomposing the gas by overheating is avoided. The enlargement of the pipe compensates the increased tension caused by raising the temperature, and on the other hand the enlargement of volume acts as a regulator to the flame. Experiments on a small scale, carried out in the office of the municipality of Turin, showed a saving of 15 per cent. due to the apparatus; further experiments, however, are required before its true value can be ascertained.

W. H. T.

Water-Gas as Fuel. By Prof. J. von Ehrenwerth.

(Gesundheits-Ingenieur, 31st July, 1884, p. 447.)

After describing the methods of generating this gas, the Author states that its utilization is again becoming a subject of interest for two reasons: 1, because it is believed that our present systems

of firing are not only inconvenient, but also very uneconomical; and 2, because illuminating gas is too dear to use for heating purposes. It is chiefly in America that this matter has recently attracted attention, and among the processes of those who have occupied themselves with the production of water-gas, the Quaglio-Dwight apparatus appears to be the most perfect; that of Bull the most capable of being brought to perfection. Bull uses a generator or gas producer and a regenerator, the two parts being connected at the top and covered with fire-resisting materials; the regenerator is filled with open tilework. The production divides itself into two periods; in the first the apparatus is heated by gases evolved in the generator, which are burnt in their passage through the regenerator. In the second period, steam is driven the reverse way through the apparatus, being superheated in the regenerator and passed through the glowing coal, by which means water-gas is formed, which is drawn off at the bottom of the furnace.

Water-gas used as fuel must be compared both with gas-producer gas and with illuminating gas. The Author gives a Table indicating the composition, products of combustion, heat-units evolved, and lost in the chimney (at 200°) in the case of water-gas and air-gas. The composition of Bull's water-gas is given as follows:—

BULL'S WATER-GAS.

	I.	II.
Hydrogen	32·50	37·50
Carbonic oxide	39·00	34·50
,, acid	0·50	3·00
Nitrogen	24·50	22·00
Oxygen	3·50	3·00
Total	100·00	100·00

From the data and calculations he adduces respecting the temperature of combustion and maximum temperatures of the gases in question, the Author concludes that water-gas is a much more concentrated fuel than air-gas from the generator; the same heat is produced therefore by less gas, with less products of combustion, and less loss in the chimney, namely 7 per cent. as against about 11 per cent.

The expenditure of carbon to produce 10,000 heat-units under each system is next considered, thus:—

	Carbon required.
For vaporising the water	0·176 parts by weight.
,, decomposing ,,	0·565 ,, ,,
,, heating the gases to 800°	0·208 ,, ,,
In the gas itself	1·000 ,, ,,

and the Author concludes that it is not possible to produce the given temperature by the use of a like amount of carbon in water-gas as when the carbon is used to produce gas-producer gas; even with the utmost allowances for future improvement of the apparatus and means of production. (The carbon required to produce

10,000 heat-units being for water-gas 1·808 parts by weight; for air-gas, 1·783 parts; for Bull's gases, 2·070; for anthracite gas-producer gas, 1·478; and by the most improved form one can conceive of Bull's apparatus, 1·515 parts by weight of carbon.

Considerations of the price of each kind of gas follow, water-gas being less than one-quarter the price of coal-gas; also of the diameter of the pipes for distribution; and the Author observes that water-gas as opposed to illuminating gas may be deemed to be undoubtedly the fuel of the future. It is, however, poisonous, in consequence of its high percentage of carbonic oxide, and its introduction must, therefore, be undertaken with great precaution.

G. R. R.

The Iron-Industry of Italy. By L. Bidou.

(Le Génie Civil, vol. vi., 1885, p. 312.)

In 1882, thirty-six mines producing iron ore were in operation, their relative importance being as follows, by provinces:—

	Mines.	Tons.
Leghorn	5	207,432
Grossetto	1	30,000
Cagliari	1	13,161
Bergamo	6	13,496
Brescia	16	6,480
Novara	1	1,000
Turin	1	330
Pisa	1	160
Como	2	21
Sondrio	2	3
Total	36	272,083

Practically there are only four groups of mines of any importance, namely, 1st, Island of Elba (Leghorn); 2nd, Monte Argentario (Grossetto); 3rd, San Leone (Cagliari); 4th, mines of Upper Lombardy (Como, Brescia, and Bergamo).

Elba Group.—This island and its iron ores have been frequently described by Burat and other geologists, and different hypotheses have been promulgated as to the character of the deposits, whose true nature has, however, been finally determined by the results of late investigations and workings. The mines have been worked from the remotest antiquity, as evidenced by the heaps of small ore left by the miners, and the remains of Roman tools and tombs found in the mines. The oldest workings are those of Rio. The mines belonged during the middle ages, and until 1815, to the Princes of Piombino, when they passed into the hands of the Grand Dukes of Tuscany, and were worked on their account until 1851, when they were hypothecated for thirty years to a joint official and financial Commission as security for a loan of 10,800,000 francs, and ultimately passed to the Italian Government, who have

leased them to a permanent syndicate managed by the Bank of Rome, at a royalty of *4s. 3d.* per ton, the annual output being restricted to 200,000 tons.

The mines, five in number, are situated on the east side of the island; their names, in order from north to south, being Rio Albano, Rio, Vigneria, Terra Nera, and Calamita; in addition to which there are some smaller ones, which are, however, unimportant. The ores include specular ore, hematite, limonite, magnetite, and spathic carbonate. Sometimes the mixture of all is very intricate; but at Rio the specular ore, and at Calamita magnetite, predominate. The vein stuff is quartz, and the ores generally contain itamum and manganese, the latter being most abundant at Terra Nera.

The ores occur in beds or masses, sometimes attaining a thickness of 70 to 100 feet, which are found at all levels, from the summits of the hills to the bottom of the valleys, though at times they only form a superficial crust filling up the inequalities in the rocks below. The surface surveys made before the assistance of borings was available, led to the hypothesis that the ores formed an immense lenticular vein, continuing in depth. The subjacent rock is a quartzose schist, covered in places by a limestone, with which the ores are most intimately associated, as for example at Rio and Calamita. During thirty years preceding 1881, a total of 3,430,000 tons was raised; and in 1868, Signor Anerio estimated the available contents of the deposits at about 20 million tons, distributed as follows:—

Rio and Vigneria	8,000,000
Terra Nera	500,000
Rio Albano	6,000,000
Calamita	6,000,000
	20,500,000

Other authorities considered these figures to be too low, and in addition the small ore left behind by the old miners was popularly supposed to be inexhaustible.

The rapid extension of the workings between 1873 and 1878 showed, however, that in almost all cases the surface ore was soon penetrated, and the barren schistose rock below reached—a discovery which alarmed the Italian Government, who were then proposing to erect large smelting works for utilizing the ore on the spot. More exact examinations of the ground were therefore made, which have resulted in the opinion that the deposits are essentially products of ferruginous thermal springs, and that the figures given above must be reduced by two-thirds—

	Tons.
Giving the total quantity unwrought at	6,050,000
The old heaps are estimated at	1,000,000
And the small ore recoverable from the sea in shallow water or "pueletta"	500,000
Total	7,550,000

At the present output of 200,000 tons, the ore would therefore suffice for thirty-five years; but at the rate shown in 1880–81, namely, 403,205 tons, it would be exhausted at the end of the present century.

The cost of production of the Elba ore, loaded on board ship, is from 6*s*. 6*d*. to 7*s*. per ton for large mine, and 3*s*. to 3*s*. 6*d*. for washed smalls from the waste; but owing to increasing difficulty, the price will probably be increased in future to about 8*s*.

Mines of Monte Argentario.—These are situate at the foot of the mountain of the same name adjacent to the lagoons of Orbetello. They have been worked since 1874. The ore, containing iron, 30; manganese, 18; and carbonate of lime 20·32 per cent., is found in masses filling caverns in a triassic limestone. The principal deposit is about 180 metres long, and from 20 to 40 metres thick; the portion above the level of free drainage is estimated to contain about 350,000 tons.

Originally the ore was worked in open cast, but subterranean mining soon became necessary, and a system of pillar-working, with stalls 8 metres high and 6 metres wide, were driven, leaving side-pillars of only 2 metres solid and 3 metres underfoot.

In March 1881, the mine fell in over an extent of 800 square metres, and when re-opened a method of filling the excavation with waste rock as the ore is removed, has been adopted, and has proved perfectly satisfactory. Owing to the friable character of the ore, the cost of working does not exceed 3*s*. 3*d*. per ton, including the filling material.

Mines of the Island of Sardinia.—The iron-ore deposits of Sardinia are very numerous, chiefly in silurian rocks, but only one, that of San Leone, has been worked to any extent. It belongs to the Société des Aciéries de la Marine (formerly Petin Gaudet and Co.), and has produced above 280,000 tons of very high-class magnetic ore, all of which is, however, consumed in France. Several other localities are mentioned by the Author, none of which could, however, deliver ores at a shipping-port below 15*s*. or 16*s*. per ton.

Mines of Upper Lombardy.—The Lombard mines produce ores of many different kinds, but only the spathic carbonates are of importance. They are found in tolerably regular bedded deposits, varying from 1 foot to 2 or 3 yards thick, partly in the lower triassic schists, and partly in the schists above them. They form a belt 10 or 12 miles long, and a few hundred yards wide, in the mountains bordering the high valleys above Bergamo and Brescia. This is one of the classic lands of open-fire iron and steel making, and, in spite of the large quantities of ore worked in bygone ages, enough remains to make the locality one of considerable promise for the future. The cost of calcined ore from the more accessible mines is given at 15*s*.–16*s*. per ton on the lake of Iseo, while that of others less favourably situated is estimated at 24*s*. on the railway at Paratico and Brescia.

There are numerous mines in Piedmont and Central and Southern

Italy, which are now of small importance. Formerly the Val d' Aosta was one of the principal centres of production, magnetic ores being worked at Como and Traversella. There are sundry other magnetic ore mines in the Valtellina, but they are very inaccessible.

Smelting Works.—In 1882 there were eighteen furnaces blowing, producing 24,778 tons of pig-iron. This was entirely smelted with charcoal, and about one-half of the total was made at Bergamo and Brescia. About 2,500 tons was consumed in foundries, the remainder being converted into iron and steel in the local forges of Lombardy and Tuscany.

In the same year[1] 90,630 tons of wrought-iron and 3,450 tons of steel were produced.

The old Berganask forge process of steel- and iron-making has now been entirely superseded by the puddling furnace, the Siemens construction being preferred, as it can be heated by waste-wood, lignite, or peat. The open-hearth steel process, in Siemens, Danks, or Pernot furnaces, has been used to some extent in Lombardy and at Piombino. The first Bessemer plant was erected in 1866, and a few others have since been added, but they have only worked intermittently and to a very small extent.

Owing to want of fuel in the interior, it seems difficult to establish large works except on the coast, where large blast-furnaces might be operated with Elba ore and English coke. The water-power available in the mountains is, however, favourable for forges, and a large establishment for the manufacture of armour-plates at Terni is spoken of as it would require only a transport of 3 tons of coke and ore per ton of finished plates from Civita Vecchia to the works, representing a cost of only 20*s*., which might be further reduced if the coke from the local lignite made in Barelli ovens could be used.

H. B.

A Cellular Structure in Cast Steel.

By — Osmond and — Werth.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, p. 450.)

The following experiments, which appear to throw some light upon the structure of steel, have been made in the laboratory of Creusot Works.

Thin plates of annealed cast steel $\frac{2}{100}$ to $\frac{3}{100}$ millimetre thick, cemented to glass by Canada balsam, are slowly acted upon by dilute nitric acid in the cold. The iron is dissolved, leaving as a residue the nitrated derivate of a carbo-hydrate in a skeleton form corresponding to the original distribution of iron and carbon in

[1] There is no indication of the source of this iron, whether it represents remanufactured scrap or is puddled from imported pig-iron.—H. B.

the metal. Microscopic examination shows this distribution to be far from uniform, and that the steel is actually made up of small granules of soft iron separated from each other by partitions of another substance containing carbon, and which is a carbide of iron. In other words, cast steel may be said to possess a kind of cellular tissue, the iron forming the nucleus, and the carbide the envelope of the cell. The elementary cells so constituted, or simple cells, are aggregated in groups into so-called compound cells, which are divided from each other in the transparent sections by thin lines which are empty spaces. These lines form enclosed polygons which are of considerable size in cast steel, but become smaller, and more and more broken and confused in the metal that has been more or less perfectly forged. As the surfaces of the compound cells, after the action of acid, are represented in section by empty linear spaces, they must in reality be due to the contact of soft iron masses without the intervention of the carbide, in which case the compound cells are said to be deprived of envelopes.

In another direction it is easy to see that the compound cells correspond to what is known as the grain of the steel, or their faces are regions of minimum cohesion, so that the fracture of a bar of steel may be defined as the surface which, in the particular part subjected to the cutting strain, contains the minimum of carbon. These observations apply only to cast steel that has been slowly cooled. By hardening the compound cells disappear entirely, the constituent elements remaining being simple cells, but the interposed carbide of iron is much less abundant than in the same steel when annealed; the remainder of the carbon having separated as hydrate, which appears to be uniformly dispersed or dissolved in the mass of the metal.

From this point of view of these experiments, forging has nothing in common with tempering in modifying the structure of steel; although the change produced in physical properties is somewhat similar. The effect produced is in permanent deformation of the cells, the nucleus being elongated in the direction of the local flow with a more or less complete dislocation of the slightly malleable envelope.

H. B.

Magnetic Separation of Minerals at Oberlahnstein.

By O. Heberle.

(Berg- und Hüttenmannische Zeitung, vol. xliii., 1884, p. 509.)

At the Friedrichseger silver and lead mine at Oberlahnstein, where a large quantity of mixed blende and spathic iron ore is produced, the separation of the minerals has for the past three years been effected by an electro-magnetic process, which is applied alike to both dressed and hand-picked ore. The latter is mainly

delivered in lumps varying from 40 to 120 millimetres in diameter, while the former ranges from 6 millimetres downwards.

The operations proper to the process are three in number, namely:—

1. Roasting.
2. Separation by electro-magnets.
3. Finishing concentration.

Roasting.—The object of this operation is to render the ore magnetic, by converting the ferrous carbonate into magnetic oxide. The larger lumps are roasted in kilns, being charged alternately with coke screenings in the usual way. Owing to the large amount of sulphur in the ore, the consumption of fuel is very small, being only 1 cwt. per 8 tons, the latter amount being daily put through the kiln, which is served by two men. The cost of kiln roasting is about 9½*d.* per ton. The roasted ore is reduced by stone breakers and crushing-rolls to particles of 5 millimetres maximum size, which are fed mechanically to the electro-magnetic machines.

The fine-grained products from the dressing processes are calcined in long flat-bedded reverberatory furnaces, an operation which is complete in about one hour and a half. Two furnaces are in use, one with working doors on both sides, and a smaller one worked from one side only. Together they roast 18 to 20 tons in twenty-four hours. The cost both for fuel and labour is much higher than in the kilns, and is computed at 2*s.* 6*d.* per ton.

Magnetic separation.—The roasted ore is spread out on a floor to cool, and separated from sintered lumps, when it is lifted by an elevator, and passed through a sizing-drum to remove particles above 4 millimetres, which are returned to the crusher, while the finer siftings pass to the electro-magnetic machines.

These differ materially from machines previously used for the same purpose, as they are continuous in action, while the magnets are kept out of contact with the material under treatment. The machine has a fixed horizontal axis, carrying a series of electro-magnets arranged radially on a frame, covering an arc of about 90°, within a brass drum, nearly, but not quite, touching the magnets, which receives motion from a belt and pulley. The outer surface of the drum is made into an elevator by a series of small ribs projecting radially. The magnets, which are so arranged that the lower series is a little below the horizontal plane, face the feeding-apron, which by an arrangement similar to that of a percussion-table, delivers the ore from the feeding-hopper in a thin stream against the excite-surface of the drum when the magnetic particles are retained and travel upwards, being kept from falling by the radial ribs, and passing over the vertical plane fall off on the opposite side, while the blende particles, not being attracted, fall down a shoot into a hutch in front. The separation is only approximate, and has to be repeated upon the roughly-classified product of the first operation, the ultimate products being—

1. Blende and quartz.

2. Spathic ore.
3. Mixed blende ore.
4. Mixed iron ore.

The two latter classes requiring further treatment. As the operation is attended with the production of much dust, the whole of the apparatus is connected with an exhaust-fan working continuously.

Sixteen machines are in use. They are arranged by series of four, of which an upper pair effect the first rough separation, and deliver to the finishing pair placed below them. The four machines in each series are excited by a Gramme dynamo of 1 HP.; the current is introduced at one end of the hollow axis of the drum, and passes out by the other. Each of the two divisions of the establishment (8 machines) treats 24 tons of roasted ore in twelve hours, producing 7 to 8 tons of blende, and 16 to 18 tons of iron ore. The rough stuff from the mine averages 12 to 15 per cent. zinc, and 20 to 22 per cent. iron, which gives dressed zinc ore of 33 per cent., and iron ore with 36 to 38 per cent. of iron, and 10 per cent. of manganese.

Finishing concentration.—The iron ore obtained as described above is not subjected to further treatment, but the blende requires further concentration in jigging machines. For this purpose, the blende freed from iron ore is delivered by an elevator to a sizing-drum, which divides it into three sizes of 3, 2, and 1 millimetre, each of which is treated on a separate jigging machine to remove earthy waste, as well as intermixed lead ore. This gives a final saleable product enriched up to 38 per cent. of zinc and lead ore, with 65 per cent. of lead, and 40 grams of silver. The fine stuff and dust from the exhauster are treated on slime buddles, and give a zinc product of 32 per cent., and lead ore of 65 per cent.

H. B.

On the Permeability of Silver by Oxygen. By L. Troost.

(Comptes rendus de l'Académie des Sciences, vol. xcviii., 1884, p. 1427.)

When a stream of oxygen is passed through a platinum tube containing within it a silver tube in which a vacuum is maintained, the whole being heated to the temperature of boiling cadmium (about 800° C.), the gas penetrated the silver tube of 1 millimetre thick, at the rate of 1·7 litre per square metre of its surface per hour. When the experiment is conducted with air, the gas from the silver tube is found to be almost perfectly pure oxygen. This shows that silver reservoirs should not be used with air pyrometers.

H. B.

On the Electrometallurgical Treatment of Copper Mattes for the Extraction of Copper. By Gerardo Badia.

(La Lumière Électrique, vol. xiv., 1884, pp. 3–11, 46–51, 92–98.)

Amongst the applications of electricity to industry, the extraction of metals from minerals is without doubt one of the most important. This method of extraction has not been attended with any practical results of moment, owing to the impossibility of procuring currents of large quantity simply and at small cost. In reality it is only the refining of copper that has been worked profitably, and this is carried out at the works of Messrs. Œschger and Mesbach, at Biache; of Mr. André, at Frankfort; of Mr. Hilarion Roux, at Marseilles; those of Moabit, near Berlin; of the North-Dutch Refinery, at Hamburg, and those of Ocker, in Hanover. The present series of articles is descriptive of the works and process as carried on by the Electrometallurgical Society of Genoa, in their property at Sestri-Levante. The Author first enters upon the description of a series of laboratory experiments, illustrative of the principles of electro-deposition of copper. He shows that the formula $E = 4{\cdot}16\, e\, C$, (where E is the electromotive force just necessary to electrolyse the salt in question; C, calories due to the reaction; *e* electro-chemical equivalent of the metal forming the base of the salt to be electrolysed), gives the means of passing from electromotive forces to calories and reciprocally, when the chemical reactions are clearly defined. Theoretically, if in the electrolysis of sulphate of copper, potentials are employed capable of furnishing energy greater than 28,200 calories, which is indispensable for the decomposition, and lower than 34,500 calories necessary to decompose sulphated water into oxygen and hydrogen, secondary work of the current is avoided. But actually, the result of electrolysing the sulphuric acid is not only the production of oxygen and free hydrogen, but also of oxides, hydrides, and other compounds which much reduce the limit of electromotive force for the decomposition of water. Two volts will decompose the water in a bath of sulphate of copper, and less than one volt will deposit copper from that solution, or from a mixture of sulphates of copper and iron with sulphuric acid; or from sulphide of copper—sulphate of copper—copper. If it were possible to have minerals or metallurgical products containing only sulphur and copper, without the presence of iron, the extraction of copper by electrolysis would not be more difficult than the refining of coarse metal. Substituting a plate of sulphide of iron for that of sulphide of copper, the metal copper begins to be deposited on the cathode when the difference of potential is much less than 1 volt. After the passage of the current the solution contains basic persulphate of iron, proto-sulphate of iron, and sulphuric acid. The deposit is of good quality so long as the solution contains 0·1 grm. of copper per 100 cubic centimetres of liquid. If this cell is provided with a good

separating diaphragm, and both compartments are filled with a solution of sulphate of copper, that solution around the cathode is only impoverished; that around the anode becomes substituted by basic persulphate of iron and free sulphuric acid, with no trace of proto-sulphate of iron. The use of anodes of sulphide of iron forms foundation for a successful electrolytic treatment for sulphate of copper solutions. This method, compared with that in use at Ocker, offers the great advantage of much less expenditure of work than is necessary for the simple electrolysis of sulphate of copper with anodes of lead or of carbon.

If the sulphide iron is replaced by anodes of sulphide of copper, less than 1 volt is required for the decomposition; sulphate of copper is produced at the anode at the expense of the copper it contains. The couple, matte-sulphate copper, gives copper with electromotive force much under 1 volt; and the deposit preserves a good quality so long as hydrogen is not given off at the cathode. And as general conclusions, the Author finds that metallic sulphides obtained by fusion lend themselves very readily to electrical conduction, except Cu_2S; the decomposition of metallic sulphides, employed as anodes, requires much less expenditure of work than that needed by the sulphate. By employing anodes of iron-copper-sulphur, such as result from the first melting ordinarily, the copper may be removed from the solution with an electrical efficiency comprised between 50 per cent. where there is no copper in the anodes, and of 100 per cent. where, on the contrary, there is no iron. With the use of metallic sulphides for anodes, all the sulphur contained in the mattes may be regained in a metalloidal state. And the extraction of copper on this method avoids the meltings necessary for concentration, and for the production of black copper and refining.

In the works at Sestri-Levante, the anodes are formed of the matte obtained directly after the fusion of the mineral, cast in iron-moulds in plates $0 \cdot 80 \times 0 \cdot 80 \times 0 \cdot 03$ metre. The melting is effected in a small furnace fed by a fan, and 15 tons of ore are operated on in twenty-four hours, yielding fifty plates, each weighing 80 kilograms. To attach the plates to the conductor, small bands of copper are cast in. The liquid of the baths is kept about 2 centimetres below the edge of the plate to prevent the connecting bands being eaten through.

The residues from the anodes, after extraction of the sulphur, are returned to the furnace. The cathodes are formed of very thin plates of red copper of $0 \cdot 70 \times 0 \cdot 70 \times 0 \cdot 0003$ metre, held in a wooden frame; and the copper is deposited to a thickness of about 5 millimetres. To produce the electrolyte, or sulphate of copper solution, very rich ores and mattes are roasted in a reverberatory furnace. The roasting is carried out so as to have more oxides than sulphates, because oxide of iron not being soluble in diluted sulphuric acid, forms very little sulphate of iron in the solution. Once prepared, the electrolytic solution is kept at normal strength of copper by circulation over roasted minerals. About four grams

of copper per 100 centimetres of solution is the quantity of copper contained at the commencement; and no change is made in the solution until, from excess of iron, the deposit of copper commences to become pulverulent, and at the same time to disengage hydrogen.

The baths are of wood, lined with lead, and are $2 \times 0 \cdot 9 \times 1$ metre (high). About a dozen of these baths are required to deposit 100 kilograms of copper a day. Proper circulation of the electrolyte is one of the most important conditions, and to effect this the baths are arranged in cascades of series of six, with a fall of 0·15 centimetres between each.

The Author points out that generating machines of very low tension are expensive, on account of the large amount of copper required to carry the current with such a low tension. The baths are therefore arranged in series, and dynamos are employed, having their magnets separately excited by another machine. Constant difference of potential is required only within certain limits, whereas constant current is necessary. The machines are driven by turbines. Twenty machines are arranged in two batteries of ten each, and each dynamo is connected with a dozen baths arranged in series. Each bath is composed of fifteen anodes and sixteen cathodes, placed at distances of about 5 centimetres. Each dynamo gives a current of 240 amperes, with a difference of potential between the terminals of 15 volts when the external resistance is 0·0625 ohm, and when making nine hundred and fifty revolutions a minute.

The following is the composition of the mattes, by analysis: Cu 34·7; Fe 38·6; S 25·3.

P. H.

The Electrolytic Reduction of Fine Copper from its Ores.

(Dingler's Polytechnisches Journal, vol. cclv., Jan. 1885, p. 199.)

The Italian Copper Mining and Electrometallurgical Company, of Genoa, which received the second prize of 5000 lire, describes the process which has been adopted for some time past at their works at Casarza, near Sestri-Ponente, as follows:

The plant includes twenty Siemens Electrolytic dynamos, giving a current of 250 amperes, at 15 volts tension, each of which serves twelve reducing baths. Part of the ore, varying in amount according to circumstances, is smelted to a coarse metal, containing copper 30, sulphur 30, and iron 40 per cent., which serves as the anode. Another part of the ore is roasted and lixiviated to form a solution containing as much copper sulphate as is required to render the ferrous sulphate of the anode useful for the electrolytic decomposition of the copper salt. The order of the operation is as follows:

Preparation of the Anodes.—The ore intended for this purpose is smelted for coarse regulus in the usual way. The regulus is cast

into thin slabs, a strip of copper being placed in the mould to form the conductor for the current. The anodes so prepared are placed in the decompositing cells, thin sheets of copper being used as cathodes.

Preparation of the Solution.—The ore roasted so as to produce the necessary sulphate for the bath is systematically lixiviated with an addition of sulphuric acid to dissolve any oxide of copper formed in roasting the liquor, containing copper and iron sulphate, is kept in tanks and added to the bath as required.

The copper sulphate is decomposed by the electric current, copper being deposited on the cathode, while the anode is attacked with the formation of iron salts and sulphuric acid, which prevents the deposit of iron and the evolution of hydrogen, so that the copper deposits in a compact form and chemically pure.

The saturation and proper composition of the solution is maintained by connecting the baths by pipes with the lixiviating vats, so that a constant and regular circulation of the liquor is kept up.

The solution has a sufficient oxidizing power to dissolve up metallic sulphides, in some cases without requiring a preliminary roasting.

The greater part of the electromotive force necessary for the decomposition of the copper sulphate is furnished by the oxidation of iron in the anode, so that for the remaining work in the bath an electromotive force not exceeding one volt is sufficient.

The exhausted anode may be utilized for the reproduction of sulphur or sulphuric acid.

When the solution is overloaded with iron vitriol it is removed from the bath, and the last traces of copper are recovered by precipitation with sulphuretted hydrogen, which is produced by adding regulus to the acid liquor. At the same time the iron salts are reduced to ferrous sulphate, and the free sulphuric acid is neutralized. The iron vitriol may be recovered by crystallizing, otherwise the liquors containing it, when freed from copper, are run to waste.

If the baths are properly arranged, and care be taken to keep the liquors in circulation at the proper strength, a maximum yield of 44 lbs. of copper per HP. employed may be obtained daily.

The process appears to be particularly well adapted for mines in mountain districts where water-power is readily obtainable, but which, owing to the difficulty of obtaining, and the high cost of mineral fuel, are unfavourably placed for smelting operations.

H. B.

On the Electrolytic Production of the Metals of the Alkaline Earths. By J. F. Holtz.

(Sitzungsberichte des Vereins zur Beförderung des Gewerbfleisses, 1884, p. 298.)

The Author has for some time been engaged in the production of magnesium by the method invented by Grätzel, of Hanover.

The source of the metal is the Carnallite of Stassfurt, which contains a large proportion of chloride of magnesium. This, when perfectly dehydrated, is subjected to a high temperature and brought in contact with the electrodes. One of them is formed by the crucible; the other is plunged into the molten mass, and a tolerably strong electric current, produced by a dynamo machine, is passed through it for about thirty-six hours.

The magnesium separates in globules under the carnallite flux. These when collected are re-melted, giving a chemically pure metallic magnesium, which is prepared in numerous forms, especially a fine powder for firework-makers. Numerous alloys have also been made by means of a standard alloy of 20 per cent. magnesium, and 80 per cent. copper. The alloy of 95 per cent. nickel and 5 per cent. magnesium is exceedingly hard, and can be worked under a steam hammer. For chemical purposes, magnesium is invaluable as an energetic reducing agent, as it decomposes water, liberating hydrogen at ordinary temperatures. The cost of the metal produced by this method is about £4 per kilogram.

H. B.

On the Variation in the Physical Properties of Bismuth in a Magnetic Field. By — Hurion.

(Centralblatt für Elektrotechnik, vol. vi., 1884, p. 855.)

Dr. Kerr's experiments have shown that a steel mirror, when placed between the poles of an electro-magnet, turns the plane of polarization of a vertical ray of light through a certain angle as soon as a current is sent through the magnet. The direction of the rotation is opposed to that in which the current circulates. The Author's researches prove that bismuth possesses the same property in this respect as steel. A mirror with a reflecting surface of bismuth is placed between the poles of an electro-magnet, the face of one pole being flat and that of the other conical. A hole is bored through the axis of each core, so that a vertical ray of light can be passed through the core with the conically-shaped pole. This incident ray is reflected back directly upon its course, and falls upon a plate of unsilvered glass fixed at an angle of 45°; the direct light passes through this plate, and the reflected beam is deviated sideways. The incident ray traverses the polarising system of a Laurent's saccharimeter, whilst the reflected light falls upon the analyzer of this instrument. The current from a Gramme dynamo can be made to pass through the coils of the electro-magnet in either direction. When the course of the current is changed, it is found that the plane of polarization of the reflected beam is rotated through an angle of about thirty minutes, the direction of rotation being the same as that of the current circulation. Part of the observed effect is

due to the glass itself, and the Author explains the means by which the actual influence of the glass can be found and taken into account.

J. J. W.

Electro-Chemical Properties of Nickel. By Dr. EMIL BOETTCHER.

(Centralblatt für Elektrotechnik, vol. vi., 1884, p. 806.)

In the first part of the Paper the Author describes some chemical peculiarities of nickel, and points out that the electro-chemical properties of this metal are of an interesting character. Nickel will neither precipitate copper from a solution of cupric sulphate, nor develop any current when joined to a copper plate in such a solution, although the heat generated by the combination of copper and sulphuric acid is not more than 29,500 calories. When either platinum or copper is immersed in sulphuric or hydrochloric acid containing a nickel plate, no voltaic electricity is generated; a current of momentary duration is obtained on connecting the metals together, but this current is due to the depolarizing effect of the small quantity of oxygen condensed on the surface of the platinum when this metal is used, and, in the case of copper, to the thin film of oxide thereon. If the latter metal is first dipped in weak acid, so as to produce a clean metallic surface, it will be found that copper and nickel, in either of the above-named acids, will not give a current. The Author electrolyzed nickel sulphate by means of an anode of lead and a cathode of nickel, and by this indirect method determined the electro-chemical equivalent of nickel sulphate. The electromotive force of this combination was only 1 volt, and the thermal equivalent of nickel sulphate proved to be only 21,300 calories.

J. J. W.

Telegraphic Apparatus. By J. MUNIER.

(La Lumière Électrique, vol. xiii., 1884, pp. 379–382.)

This is a corrected statement of the work obtained from telegraphic apparatus actually in use in the French service. The Author makes two great divisions, into signalling and printing apparatus, and gives the following list of systems in order of speed:—

	Number of Characters a Minute.	Theoretical Production of Messages.	'Practical' Production.
1. Baudot (sextuple)	780	360	200 to 250
„ (quadruple)	520	240	130 „ 180
2. Meyer (octuple regulated to 90 revolutions)	720	332	200 „ 250
Meyer (sextuple)	600	276	180 „ 200
„ (quadruple)	400	184	120 „ 150
3. Wheatstone	300	138	120
4. Hughes	175	80	60 „ 70
5. Morse	75	35	25 „ 30
6. Needle	50	23	18 „ 20

The number of forty to fifty messages attributed to the Hughes system is quite erroneous, as is that of seventy-five to Meyer's. A Meyer octuple apparatus produces as many, if not more, than a Baudot sextuple, similarly as a Meyer sextuple will produce more than a Baudot quadruple. The sole advantage of the Baudot is that it prints.

If the number of emissions of current to produce a given number of characters be the standard, the Hughes is far in advance.

To produce one character in each system requires—

In Hughes system	. . .	1 emission of current.
„ Meyer „	. . .	3 to 4 „ „
„ Morse „	. . .	4 „ „
„ Baudot „	. . .	5 „ „
„ Wheatstone „	. . .	6 „ „
„ Needle „	. . .	6 to 7 „ „

For signalling apparatus, in order to obtain the average of emissions, it is necessary to know the average presentation of each letter in the formation of words, and this is for:—E 219, R 118, N 108, A 107, S 106, I 105, T 98, U 82, O 80, L 69, D 52, C 48, P 46, M 46, É 39, V 27, G 17, H 17, F 15, Q 15, B 14, X 8, Y 6, Z 6, J 5, K 1.[1]

Given a wire capable of three hundred thousand emissions an hour, and a mean of one hundred and thirty emissions a message—

The Hughes should give	. . . .	2,308 messages.
„ Meyer „ „	. . . .	666 „
„ Morse „ „	. . . .	576 „
„ Baudot „ „	. . .	462 „
„ Wheatstone „	. . . .	385 „
„ Needle „ „	. . . .	355 „

Despite the most ingenious mechanical arrangements, the producing power of all the apparatus remains inferior to that of the lines.

The Author terminates his remarks by a statement of the production of each apparatus actually in use per hour and per employee.

	Number of Messages an hour.	Total Number of Employees occupied at the Two ends of the wire.	Mean Number of Messengers.
Baudot sextuple . .	240	16 (12 operators, 2 writers, 2 directors)	$\frac{240}{16} = 15$
Meyer sextuple . .	180	12 operators (including 2 directors or superintendents)	$\frac{180}{12} = 15$
Wheatstone . . .	120	8 (6 operators, 2 directors)	$\frac{120}{8} = 15$
Hughes	60	4 operators	$\frac{60}{4} = 15$
Morse	30	2 „	$\frac{30}{2} = 15$
Needle	20	2 „	$\frac{20}{2} = 10$

[1] This is, of course, for the French language.—P. H.

It seems that, whichever the system used, the number of messages per employee is practically the same. With the high speed apparatus of Baudot, Meyer, and Wheatstone, the average is reduced by the presence of special employees. termed directors, who keep the apparatus in working order. These directors are more or less necessary; the Baudot apparatus especially refuses to work if he be absent half an hour. This is a great inconvenience, and points to considerable improvement still to be effected.

P. H.

Electric Fire-Alarms. By F. Evrard.

(La Lumière Électrique, vol. xiii., 1884, p. 85.)

The electric fire-alarm systems of different countries are classed by M. Bartelous under the following heads:—

1st System.—Giving the alarm to a fire-station or to a police office, which is in telegraphic communication with the branch and head stations of the fire-brigade.

2nd. Electric communication from the various police-stations to specially constructed alarm-boxes, which may be worked automatically or require to be put in action by an official of the force.

3rd. Private apparatus, enabling one to give the alarm from one's own house.

4th. Automatic apparatus, giving the alarm on pyrometical principles.

5th. Application of electricity to accelerate assistance.

Nearly all large towns come under the first category, and have their police offices communicating directly with the chief and branch fire-stations. To make this system thoroughly efficient there should always be an alarm-office within 300 yards. The telegraphic system has the advantage of preserving a record of the indication and orders given, by which means it is easy to ascertain who is responsible for the alarm.

In Paris the chief station of the fire-brigade is connected, not only with the branch stations and police offices, but also with each of the following:

1. The head-office of the water-supply.
2. The head-quarters of the "*Assistance Publique.*"
3. The "*Préfecture de Police.*"
4. All telegraph offices.

It has also been proposed by the "*Union Syndicale*" that messages relating to fires should be transmitted free of charge by all telegraph offices.

The system which comes under the second heading is that employed to a great extent in Germany (Francfort-on-the-Main, Munich, Hamburg) and also at Amsterdam. In Belgium Verviers alone has a system of the kind, though Brussels has lately adopted it in theatres and public buildings. New York

possesses a great number of alarm-boxes. These can, however, only be opened by numbered keys furnished to responsible persons, and when the alarm has been given the key cannot again be withdrawn without the use of a duplicate, the possession of which is confined to the police and fire-brigade, thus preventing all false alarms.

Members of the Stock Exchange and other people in London who are subscribers to private telegraph and telephone companies, have the power of obtaining assistance through these channels, under the third system.

Under the fourth heading come a number of apparatus working on the principle of expansion. When a fire breaks out the heat generated causes the completion of a circuit by expanding some part of the apparatus so as to come in contact with another portion, and in this way the alarm is given. There are, however, many disadvantages in this system. To make it properly efficient a great number would be required, whilst their liability to get out of order would necessitate a great deal of looking after. They would be of great use, however, if placed near enough to the possible sources of a fire, or where there was a danger of spontaneous combustion.

A very ingenious system in use in the United States may be mentioned under the fifth heading. On the alarm being given the current causes the doors of the fire-station to open, the horses leave the stable and place themselves before the engine, the harness, which is suspended over it, drops on to them, and in 5 seconds the engine dashes out. Thus in less than a minute after the alarm has been given the first engine may be on the spot. It was next thought, that, by the use of water on the point of ebullition, some of the time required to get the engine under pressure might be saved. The five minutes following the alarm are, in the opinion of the heads of the Metropolitan fire-brigade, more important and valuable than the five succeeding hours. To save a few minutes at this critical moment the San Francisco brigade have a boiler in the basement which is connected, by means of an inlet and an outlet pipe, with the boiler of the fire-engine, and kept in a constant state of ebullition. The connection between these boilers is broken off by the current which gives the alarm.

O. C. D. R.

Trials made at Turin and at Lanzo on the Distribution of Electric Light to Great Distances.

By H. Tresca, Hon. M. Inst. C.E.

(Comptes rendus de l'Académie des Sciences, vol. xcix., 1884, pp. 549–50.)

An electrical Exhibition has been held at Turin, and important prizes have been offered by the Italian Government and by the

City; and the Author is empowered by the jury to make known to the Academy the following facts:—

Messrs. Gaulard and Gibbs have established between the Exhibition, the station at Lanzo and intermediate stations, a circuit of 80 kilometres length, with a chrome-bronze wire, of 3·7 millimetres diameter. This wire is traversed by alternating currents produced by a Siemens machine of 30 HP. The following lights were worked from the circuit with the intervention of Messrs. Gaulard and Gibbs' secondary or induction apparatus: at the Exhibition, 9 Bernstein lamps, 1 Soleil lamp, 1 Siemens lamp, 9 Swan lamps, and 5 other Bernstein lamps at a short distance, all however needing very different electromotive forces. At the station of Turin-Lanzo, 10 kilometres distant, 34 Edison lamps of 16 candles, 48 of 8 candles, and a Siemens arc lamp. Later there were added at the station at Lanzo, 40 kilometres distant, 24 Swan lamps of 100 volts. The lighting was perfectly regular, and easily independently extinguished and illuminated.

P. H.

An Artificial Resistance for Use in the Circuit of Dynamos.

By. W. Vollbrecht.

(Elektrotechnische Zeitschrift, vol. v., 1884, p. 416.)

The rheostat described by the Author is used in the external circuit of a dynamo-electric machine for determining the current-strengths corresponding to different resistances in the outer circuit, the minimum resistance that would stop the motor, and other data of a like kind. In place of German silver wire, a braided metallic band formed of wire of low conductivity is employed for the resistances. The cross threads of this band are good conductors of heat, and tend to disperse it rapidly. In a box are fitted ten rectangular flat wooden frames held together and to the wooden cover of the box by means of laths; on these frames the braided metallic bands are wound, and at various points of the latter, corresponding to equal increments of resistance, copper wires are soldered, the other end of these wires being attached to a series of contacts, which are fixed in a semicircle on the outer face of the wooden cover. Each metallic band is about 10 millimetres broad, and four of them are connected in multiple arc in such wise as to give a total length of 200 metres of band having a resistance of only 1 ohm, which is the maximum resistance contained in the box. Eleven contact studs are provided; one, marked "zero," is in metallic connection with a suitable terminal, and the remaining ten bear consecutive numbers from 0·1 to 1·0, so that any resistance can be inserted from one-tenth to one ohm, increasing by one-tenth at each successive contact. A brass lever with contact spring is fitted in the middle of the cover and can be moved over the contacts. The centre of this lever is in connection with a

second terminal. The sides and cover of the box are pierced with holes, which allow the heated air to escape. In order to prevent an interruption of the current and consequent spark, the copper spring underneath the lever is made so broad that the space between two contact studs is bridged for a moment while the lever is being moved from one to the other. This form of rheostat has given very good results, and is an improvement on the German-silver resistance-coils usually employed.

J. J. W.

The Dangerous Effects of High-Tension Currents.

By E. HOSPITALIER.

(L'Électricien, vol. ix., 1885, p. 97.)

Mr. d'Arsonval has proposed a method for preventing the dangers to life which are occurrent in the use of high-tension currents; it consists in inserting as a shunt, between the poles of a continuous-current machine, a series of voltameters consisting of plates of lead, or other polarizable material, in vessels of acidulated water, of such number that the electromotive force due to their polarization exceeds that of the machine; this circuit will not be traversed by the ordinary current, but as soon as the main circuit is interrupted, the extra current thus caused will pass at once.

This has been arrived at as a result of three theorems enunciated by Mr. d'Arsonval:—

(i.) That a battery and a machine producing in a simple closed circuit currents of the same intensity and electromotive force, are not equally dangerous.

(ii.) That the above is also applicable to the case of machines of different types.

(iii.) That a current of given intensity, dangerous in one circuit, is not necessarily so in another circuit.

All the above theorems are deducible from the assumption that the dangerous effects are caused by the extra current induced on interrupting the circuit, the intensity of which will be a function of the self-induction of the machine or circuit.

If, then, these dangers were due to the interruption alone of the circuit, the method proposed would prove a veritable safeguard in the way indicated, but unfortunately death has, in well-authenticated cases, resulted from contact with a closed circuit in which was maintained a current of high electromotive force, without any interruption of the main circuit.

There is no doubt that there are numerous cases in which the application of this method will prove extremely beneficial; and perhaps, especially in experiments as to the limit of electromotive force, which may be considered free from effects fatal to human life; as by this means any given electromotive force cannot in any circuit be exceeded.

In a subsequent communication, Mr. d'Arsonval discusses the use of a lightning-discharger connected between the terminals of the machine, but by experiments he shows that no spark passes unless a condenser of some capacity is also introduced; and then, that the effects from the shock may be just as fatal, guinea-pigs having, in the latter case, succumbed after a few discharges of quite a low-tension current.

F. J.

Circulation-of-Liquid Battery. By J. Carpentier.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 849–51.)

This is a single-liquid bichromate battery, in which circulation is maintained by a siphon arrangement, which may be considered as a siphon having both branches in the same exciting liquid. If the liquid is homogeneous it remains in equilibrium; but as it becomes charged with zinc, circulation is set up. In construction a tubular form of element has been adopted. The carbon is a tube, in the interior of which is suspended a rod of zinc. This internal space constitutes the long leg of the siphon. In the trial apparatus the second branch is the annular space between the carbon and an enveloping tube of glass. Communication between the two branches is established by a crown of holes in the upper part of the carbon. The siphon is started by aspiration.

P. H.

An Improved Switch-board for Telephone Central Stations. By Dr. Victor Wietlisbach.

(Centralblatt für Elektrotechnik, vol. vi., 1884, p. 756.)

In telephone central stations a separate switch-board and one attendant for each group of subscribers have hitherto been used. Communication between any two subscribers of group No. 1, for example, was made in the usual manner, but if A of group No. 1 wished to telephone to B of group No. 2, the attendant in charge of the switch-board 1 had to arrange for the necessary connections, either verbally or by writing with the official at board 2. By means of the American multiple switch-board described in the Paper, the work in large central stations is simplified, as all kinds of connections can be so effected thereat that the attendant at each board is quite independent of all others in the station. The system of groups is maintained, each consisting of two hundred or more subscribers, and at each board there are contacts for all the remaining subscribers, whose wires are brought into the station. The Paper is illustrated by diagrams which show the connections of the board.

J. J. W.

On the Prevention of Local Magnetic Influences in Measuring-Instruments. By Professor Dr. Dorn.

(Elektrotechnische Zeitschrift, vol. v., 1884, p. 403.)

The magnetic properties of the metals used for the wires, dampers, magnet-frames, &c., of electrical measuring-instruments are likely, from various causes, to vitiate the measurements obtained with such apparatus. When the material is carefully selected, the disturbing effect of permanent magnetism will be unimportant, but the induced magnetism, especially that due to the magnets of the apparatus itself, will give rise to errors. The mass of metal composing the coils and dampers, which surround the magnet, are initially in a symmetrical position relative to a vertical plane through the axis of the magnet, and may be of the same specific inductive capacity throughout. In this case the induced magnetism will not subject the magnet to any moment of rotation, but directly the symmetry is disturbed, owing to a deflection of the magnet, a moment of rotation results. The Author remarks that the surest method of avoiding these local disturbing influences is to discontinue the use of metals in immediate proximity to the magnet. White marble is diamagnetic, and the Author regards this substance as more suitable for certain parts of electrical measuring-instruments than serpentine stone, which is strongly magnetic, and not so good an insulator as marble. In most instances, however, metals must be used; and as electrolytical copper is almost always diamagnetic, it can be used with advantage for the frames of heavy magnets, the setting of mirrors, &c. The massive dampers of aperiodical galvanometers can be made of separate pieces of this metal, ground to fit one another, so as to form the required shape, and then held together by rivets of the same material.

J. J. W.

Volt- and Ampere-Meters. By Engineer Hummel.

(Centralblatt für Elektrotechnik, vol. vi., 1884, p. 777.)

The Author has devised two or three forms of ampere-meters with fixed and movable coils disposed in a special manner, but these instruments have been abandoned in favour of a more effective and simpler one, the indications of which depend on the action of a solenoid, on a tube made from sheet iron 2 millimetres thick. This tube is fitted with an axis, which works between centres so arranged that the tube rests eccentrically in the solenoid, and with its axis parallel with the latter. When a current is sent through the fixed solenoid, the magnetic effect, and consequent attraction, are greatest on that side of the solenoid, say *a*, which lies nearest to the tube, and the latter is turned eccentrically on its axis until the attractive force of the solenoid is balanced by the weight of a

counterpoise attached to the pointer, which is fixed on the axis of the tube and moves with it. The weight of the movable system in this instrument is about 2½ grams. As the effective force is large in proportion to the moving mass, and scarcely any pressure exerted on the bearings, the simple arrangement of mounting the tube between centres could be employed. The scale, on which the deflection of the pointer is read off, is divided into unequal parts, so that, at the zero end, the divisions are closer together than those at the other end of the scale. This graduation suits the practical requirements met with, for example, in electric lighting by means of glow-lamps, for in the measurement of the differences of potential in an installation of this kind, only that part of the scale corresponding to a range of 90 to 120 volts would be required, and the deflection produced by 30 volts would be 60 millimetres, so that an error of 2 millimetres in the reading would be equivalent to 1 volt only, or about one-hundredth of the total force under measurement.

J. J. W.

On an Ampere-Meter, based on the Peltier Effect. By H. Hesehus.

(Exner's Repertorium der Physik, 1885, vol. xxi., p. 151.)

This instrument consists essentially of a differential air-thermometer, the two bulbs of which enclose the opposite ends of a thermopile; so that when an electrical current is passed through the thermopile, it traverses the junctions in each bulb in opposite directions; and as a result of the Peltier effect, there will be a cooling at one set of junctions, and a heating at the other; the action of this on the gas enclosed in the bulb will cause a movement of the mercury index in the fine tube which connects the two bulbs. The heating of the bars themselves by the current will be equal in each tube, and therefore such effect will be balanced.

For alternate currents, the instrument can be used as an ordinary air-thermometer, and the movement of the index will be then proportional to the square of the current.

In an instrument of this type constructed for the Author, twelve bars of iron and nickel, soldered together to form two pairs of series, are bound together with cement, so as to form a solid prism, and on to its ends were cemented glass vessels, each entered by two small tubes, one in each communicating with the U tube containing the mercury index, and the others through a pinch-cock with the outer air. By comparison with one of Ayrton and Perry's ammeters, a movement of one division of the scale indicated a current of 0·68 ampere.

The following advantages are claimed for this form of instrument: that it gives the intensity of the current at each moment, thus superior to a voltameter; it can be simply and cheaply con-

structed; it can be used as indicated above, for either direct or alternate currents; and, especially, that it is absolutely unaffected by any magnetic field, and can therefore be used in close proximity to dynamo machines.

F. J.

A New Method for Determining the Gravitation-Constant.

By A. König and F. Richarz.

(Exner's Repertorium der Physik, 1885, vol. xxi., p. 208.)

A delicate balance is to be fixed on the upper horizontal surface of a leaden parallelopiped, of such form that its attraction can be easily integrated; vertically beneath each scale-pan holes are bored, and wires passing down through them connect two scale-pans just below the lower surface to the two which are just above the upper surface.

A mass in the upper right-hand scale is first balanced by weights in the lower left-hand scale; the same mass is then removed to the lower right-hand scale, and balanced by weights in the upper left-hand scale. The difference of these two weighings is a function of the vertical component of gravity at the place, and the attraction of the leaden body. A combination of these results with similar ones obtained before the erection of the leaden mass, gives the value of the attraction of such mass, from which, and its position with respect to the earth, g, the force of gravity at the place can be calculated.

The superiority of this over previous methods results from the compactness of the arrangement, so that the whole system of scale-pans and leaden mass can be easily enclosed in a glass case, thus preventing all disturbing effects of temperature and air-currents, and, further, from the form of the resultant equation, by which the limits of error for a given mass are reduced four-fold.

F. J.

On the Electrical Differences between Liquids, and on the Effect of Air in Electrometric Measurement of these Differences.

By E. Bichat and R. Blondlot.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 701–3.)

Applying to electro-capillary phenomena the principles of the conservation of energy and of electricity, Lippmann has established two distinct equations relative to the properties of the surface of contact between mercury and an electrolyte. Helmholtz has remarked[1] that there arises from one of these equations

[1] "Monatsberichte der Berliner Akademie," 3 Nov. 1881.

that if by a suitable polarization the maximum value be given to the capillary constant of the contact surface, the mercury and electrolyte are at the same potential; and Garbe has by analogous reasoning arrived at nearly the same conclusion.[1]

The Authors proceed to show that there may be founded on this proposition a method for measuring the electrical difference between liquids by intercalation in the circuit of a Lippmann electrometer, in substitution for the acidulated water of which is used a solution of the electrolyte proposed, that electromotive force which by trial gives the maximum rise of the meniscus in the capillary tube. At this moment, according to Helmholtz, the electric difference at the meniscus is nil. The intercalated electromotive force gives the normal value. This method is unsuitable where electrolysis results before the maximum is attained.

The air has no part in this method of measurement. Maxwell has remarked that in all electrometric processes analogous to Volta's it is probable that the measurement is the algebraic sum of three electric differences, one being the true difference between the substances under experiment, the two others those between air and each of the substances. The Authors state that their experiments confirm Maxwell's view.

P. H.

On the Action of the Gramme Ring. By A. Gravier.

(La Lumière Électrique, vol. xiv., 1884, pp. 21, 22.)

Influence of the quantity of Iron in the Ring.—In a Gramme machine, of type A for instance, if the iron core of the ring has a section nearly equal to that of the core of the electro-magnets, its working presents remarkable peculiarities. Suppose the machine to be externally excited. When the ring is set in motion and the induced circuit closed through a volt-meter, the induced currents produce polarities (at right angles to the line through the centre of the pole-pieces) which are very weak, but which become more powerful as the current in the ring is increased by variation of the external resistance. For a current of 30 amperes, these polarities are such that the currents induced by the magnetic field of the electro-magnets are partly annulled by the inverse induction due to the magnetic field of the ring; and (calling the two quadrants counted in the direction of the motion of the ring from the polar line respectively to the line of the brushes $b\ b'$ and $a\ a'$) the currents produced between $b\ b'$ and $a\ a'$, circulate, between $b'\ a$ and $a'\ b$, so as to arrive at the brushes, as in a simple conductor; the seat of the useful induction is concentered in the parts of the ring $a\ a'$ and $b\ b'$. To overcome this inconvenience, the Author designed the placing of two brushes at 90° from

[1] "Comptes rendus de l'Académie des Sciences," vol. xcix., 1884, p. 123.

the first. There result from this the following consequences: the passage of the current in the two parts $a' b$ and $b' a$ is avoided; there is an increase of 10 volts absorbed by the useless circulation; the resistance of the ring is reduced one-half; if the 10 volts gained are useless, there may be with the same excitation a diminished velocity; the use of four brushes admits of utilizing the machine as if it had two distinct circuits that may be united in parallel or in series. This action explains the phenomena of the armature invented by Messrs. Damoiseau and Petitpoint.

P. H.

Conditions of Equilibrium of a Liquid Plate submitted to Electromagnetic Action. By G. LIPPMANN.

(Comptes rendus de l'Académie des Sciences, vol. xcix., 1884, pp. 747–749.)

When a liquid, traversed by electric currents, is at the same time submitted to the action of magnets arranged in its neighbourhood, it experiences electro-magnetic forces tending to displace each current element. These forces have their points of application in the interior of the liquid mass. By their intervention may be realised the cases of equilibrium, or of more general movements, that often present themselves in hydrostatics; besides, the conditions of equilibrium may serve to illustrate properties of intersections rendering a function uniform in a given space.

Let a horizontal and infinitely thin plate of a liquid conductor be traversed by electric currents passing from electrodes arranged in a known manner, and placed in a vertical magnetic field of uniform intensity, H. It is proposed to find the conditions of equilibrium. At a point of the liquid of which the rectangular co-ordinates are $(x\ y)$, the quantity of the current is a dimension of which the components parallel to the axes are $K \frac{\delta V}{\delta x}$, $K \cdot \frac{\delta V}{\delta y}$, K being a constant, and V the electric potential at the point considered. V is such a function of x and of y as to satisfy the equation.

$$\frac{\delta^2 V}{\delta x^2} + \frac{\delta^2 V}{\delta^2 y} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The electro-magnetic force is normal to the direction of the current, and has for components

$$X = -H K \frac{\delta V}{\delta y} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$Y = H K \frac{\delta V}{\delta x} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Calling p the hydrostatic pressure at the point $(x\ y)$, the necessary conditions of equilibrium are—

$$X = -\frac{\delta p}{\delta x} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$Y = -\frac{\delta p}{\delta y} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Are these conditions sufficient? To ascertain this, from (4) and (5) may be deduced—

$$\int (X\,dx + Y\,dy) = \int \frac{\delta p}{\delta x}\left(dx + \frac{\delta p}{\delta y}\right) dy. \quad . \quad (6)$$

It is requisite that the second member, which is only the variation of the hydrostatic pressure p, should be a uniform function of x and y. This is then true of the first member. From equations (1), (2), and (3),

$$\frac{\delta X}{\delta y} - \frac{\delta Y}{\delta x} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The condition of integrability (7) is therefore a consequence of equation (1). For the function of x and y, represented by the first member of equation (6), to be uniform, it is sufficient that the space occupied by the liquid should have a convenient form, or that it should be divided by appropriate intersections. These intersections are realizable under the form of partitions impermeable to the liquid, but permeable to electricity. Then equilibrium will exist. It is also shown that the curves p = constant are orthogonal or conjugate to curves V = constant.

It results that whatever may be the form of the space occupied by the liquid, or the distribution of the electric currents, it is necessary and sufficient for equilibrium that this space should be limited by partitions arranged as intersectors, that render the conjugated function of the electric potential uniform. The law of the pressures developed on the contour-surface is that these pressures have values conjugates of those of the electric potential. It follows that if the given space is in simple connection, there is always equilibrium, exemplied in the case of the mercury galvanometer submitted by the Author to the Academy. Inversely, in the experiments of Faraday, and in Bertin's apparatus for showing the electro-magnetic rotation of a liquid, the space occupied by it is always in multiple connexion.

P. H.

Note on a Condenser. By Dr. A. Tobler.

(La Lumière Électrique, vol. xiv., 1885, pp. 486–8.)

The condenser in question was constructed by Messrs. Berthond, Borel & Co., of Cortaillod, Switzerland, and was of the nominal value of 1 microfarad. According to the Report on the Electric Exhibition of Munich,[1] its dielectric consists of paper, treated with a mixture of resin (colophonium) and oxidised linseed oil. This material presents the special advantage of retaining the smallest possible residual charge, that is, its absorptive power is exceeding low.

The Author carried out investigations as to the following: influence of duration of charge; of charging potential; insulation; residual charge; value of subdivisions.

Influence of duration of charge:

P = 2 Daniell elements.
Capacity = 1 mfd. T = 13·5° C.

Duration of charge.	Deflection.
2 seconds	166
5 „	166·5
10 „	167
20 „	167
30 „	167
120 „	167

At the end of ten seconds, therefore, the condenser took its maximum charge.

As to the influence of the charging potential, the Author at first experienced some differences, although identicality of cells was carefully verified; but by charging from the same battery shunted with three resistances of 5,000 ohms each, at different points of the circuit, nearly perfect concordance was established with proportionality to potential.

Charged with 2 Daniells, the maximum loss of charge in one minute was 1·5 per cent., a result, said by the Author to be rarely attained.

Time of charge.	Immediate deflection.	After 1 minute.	Percentage loss.
10 seconds	167	164·5	1·5
15 „	„	165	1·2
20 „	„	165	1·2
30 „	„	166	0·6
40 „	„	166	0·6
50 „	„	166	0·6

It is curious to note that the loss diminishes with increasing times of charging.

For residual charge, the condenser was charged during ten

[1] "Officieller Bericht eiber die Eleketricitats-Austellung in München," 1883, pp. 82 and 151.

seconds, discharged during a given time, insulated for two minutes, and again put into connection with the galvanometer.

P = 2 Daniells; Cap. = 1 mfd.; Temp. = 16° C.

Deflection.	Time of discharge.	Charge remaining after 2 minutes' Insulation.
1,700	1 sec.	10
"	10 "	4
"	15 "	2
"	30 "	1
"	60 "	0·75

P. H.

On the Avoidance of Dangers from Mechanical Generators of Electricity. By A. D'ARSONVAL.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 239–241.)

The increasing use of powerful electro-magnetic generators has caused several accidents, followed sometimes by death. It is now sought to regulate the use of electricity, and to determine experimentally the practically dangerous quantities and tensions. The problem thus stated is badly put, and is not, as the Author seeks to show, susceptible of any solution.

A battery and a machine giving in a rectilinear circuit two currents, having the same tension and same quantity, are not equally dangerous. The machine produces, under interruption of the circuit, a far more dangerous shock, due to the self-induction in the machine itself, as exhibited in the extra-current.

Two machines giving currents having the same tension and quantity on similar circuits may be unequally dangerous. And a current not dangerous on one circuit may be dangerous on another. If an electro-magnet be interposed in the circuit, so as to increase the self-induction, the danger will be increased.

To avoid all danger the Author puts in derivation, or shunt, at the terminals of the generator, a series of voltameters with leaden plates charged with aciduated water, in sufficient number that the electromotive force of polarization may be greater than the maximum electromotive force of the machine. This shunt is absolutely impassable to the direct current, but is easily traversed by the extra current. At the instant of interruption of the circuit, the extra current passes across the voltameters, and the human frame is spared.

P. H.

On a Galvanometer with Indications Proportional to Current Quantities. By MARCEL DEPREZ.

(La Lumière Électrique, vol. xiv., 1885, pp. 401–3.)

The experiments undertaken by the Author at Creil in electric transmission of power, have called for instruments, giving current-quantities and differences of potential with precision, and of

simple construction, easy to manage, exact and rapid in their indications. The instrument described is a practical modification of the d'Arsonval-Deprez galvanometer, and belongs to the class of apparatus with a moving circuit, but is so modified as to make its deflections exactly proportional to the current-quantity, even when these extend to 120°.

A "multiplier" frame [that in which the current passes, and formed of coarse or fine wire, as the instrument is intended for use either as am-meter or volt-meter] is suspended between two metallic wires, tightly stretched on the same vertical line. The current enters by one of these wires and leaves by the other. In the interior of this frame is suspended a tube of soft iron, with thick sides, the axis of which coincides with that of the suspension wires. Externally to the frame are two pieces of soft iron, cut circularly, following concentrically the circumference of the tube, and strongly polarized by a bundle of magnets.[1] The vertical sides of the multiplier frame move in a restricted annular space, in which the magnetic field is very concentrated and uniform. All the lines of force are normal to the tube, so that if the moving frame be traversed by a current, the mechanical tort developed by this current will be independent of the position of the frame, under the condition that its sides are always within the same magnetic field, that is, the amplitude of angular movement must be less than a semi-circumference.

The galvanometric constant remained sensibly the same for ranges between 10° and 60°, varying less than 1 per cent. of its mean value.

P. H.

On Galvanometers with Curved Frames. By A. Gaiffe.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, p. 794.)

The Author gives only the following general description. The wires of the multiplier frames, which are wound in grooves, form, above and below the needle, in planes parallel to its plane of oscillation, two figures that recall two caustic-curves (reflexion curves) having their cusps in the neighbourhood of the axis of rotation of the needle. By reason of the form of these curves, determined empirically, the magnetic axis of the needle, whatever its direction, always cuts at nearly the same angle that part of the frame to which it is adjacent; the proximity of wire and needle, and consequently their reciprocal action, increases at the same time as the action of the terrestrial couple.

P. H.

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[1] The system in fact consists of a coil of wire, of rectangular elevation rotating on a central line parallel to its sides, which line is the axis of two concentric tubes of soft iron, in the annular space between which the sides move. The outer tube is split into two parts [also parallel to the axis] which are oppositely magnetized.—P. H.

Means for taking the Potential of the Air. Electromotive Force of Combustion. By H. Pellat.

(Comptes rendus de l'Académie des Sciences, vol. c., 1885, pp. 735–737.)

The Author's researches have reference to the rapidity with which the apparatus employed to take the potential of a mass of air follow a variation of potential. Mascart's quadrant electrometer being used, it is found that a water-dropping collector takes a relatively long time to charge the needle to the potential of the air. With an outflow of 8 litres of water in twelve hours, it needs about six minutes for the electrometer to show $\frac{8}{10}$ of the variation of the potential produced; with an outflow of 12 litres it needs five minutes for the needle to attain nearly the potential of the air. The combustion of a filter-paper wick impregnated with nitrate of lead, as used for portable electrometers, is a still less rapid means of taking the potential of the air, and is unreliable.

The Author was led by certain results to try a gas-flame burning at the extremity of a metallic nipple, insulated and connected to the electrometer, and this was found to give nearly instantly the potential of the air to the needle, or more nearly correctly, the variations of potential.

To obtain the potential it is necessary to know the electromotive forces to which the combustion of gas may give rise. That this might be ascertained under well-defined conditions, the burner was placed in the interior of a large metal cylinder, closed above with a plate of the same metal, only with the necessary openings for draught. This apparatus behaves like the cell of a battery; its electromotive force depends (1) on the nature of the gas burned, (2) on the nature of the metal constituting the burner, (3) of the interior surface of the cylinder. The following are some of the results:—

Gas.	Burner.	Inductor.	Volts.
Hydrogen	Brass	Copper	0·30
"	"	Zinc	0·58
"	Zinc	Copper	0·09
"	Platinum	"	0·45
"	"	Platinum	0·10
Illuminating gas	"	"	0·94
"	"	Copper	1·72

The burner is the positive pole, the inductor the negative. The resistance of these elements was measured by the discharge of a Leyden jar; with a gas flame 0·01 metre height burning in an inductor of 0·13 metre diameter, it was 115,000 megohms; with an inductor of 6·5 centimetres, 69,000 megohms. A chain of metals, incandescent gas and coal-gas, does not follow the voltaic series of tensions.

P. H.

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TO THE

MINUTES OF PROCEEDINGS,

1884–85.—Part II.

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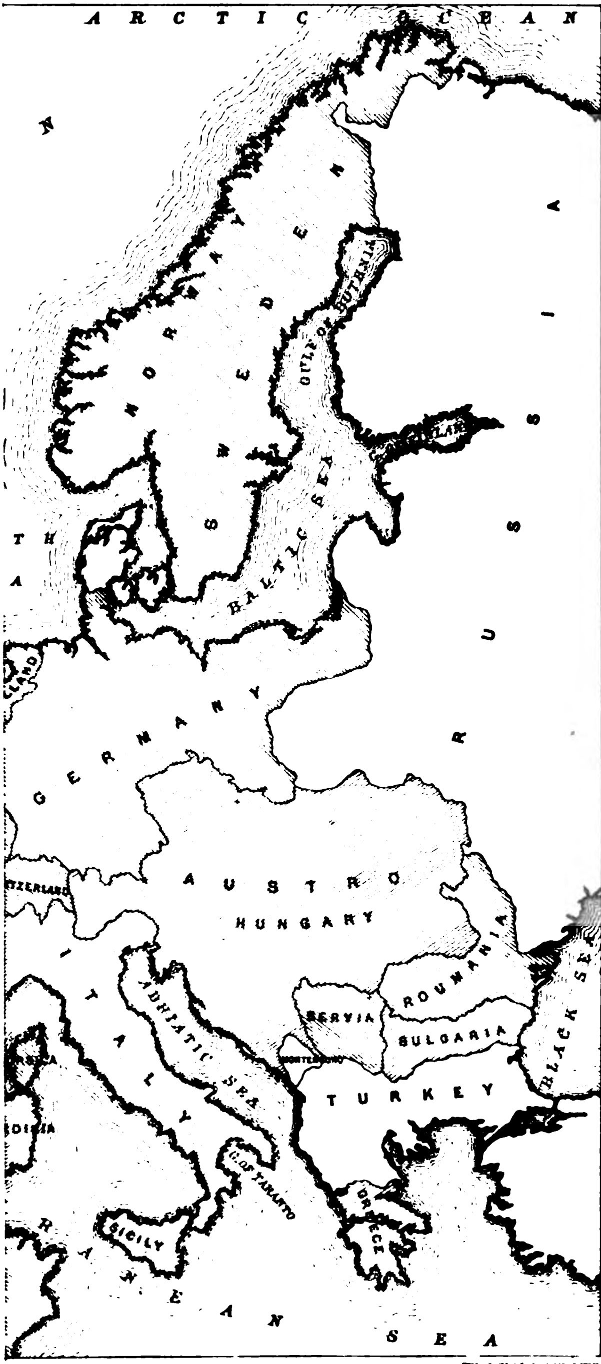

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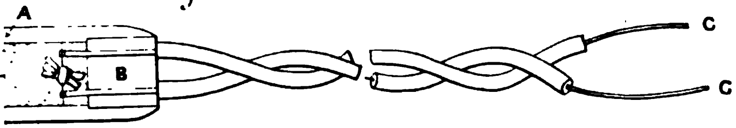

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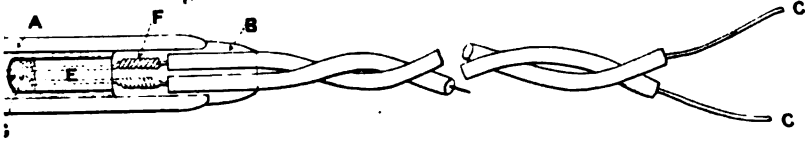

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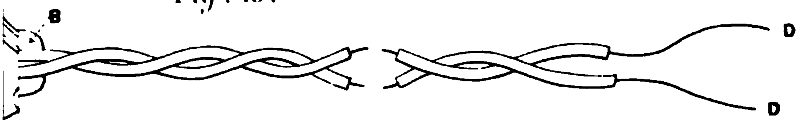

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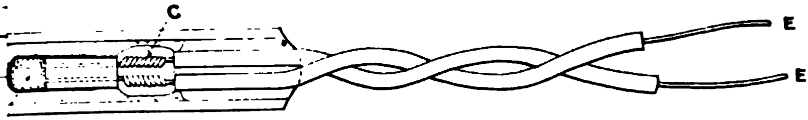

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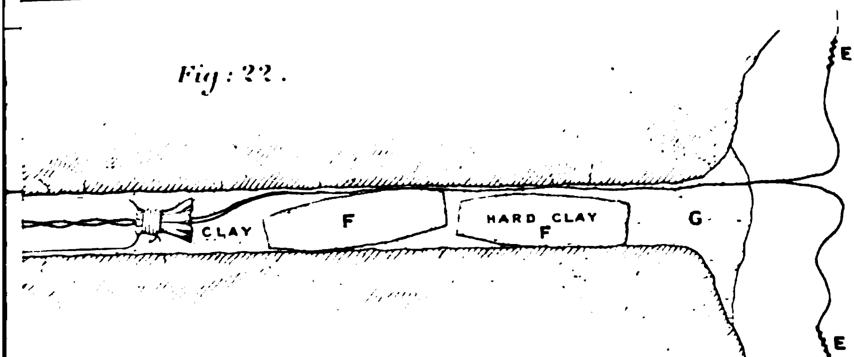


Fig: 21.

Friction at different Temperatures.

BRIGHT BRASS DISK, 20" DIAMETER, 3" SPACES.

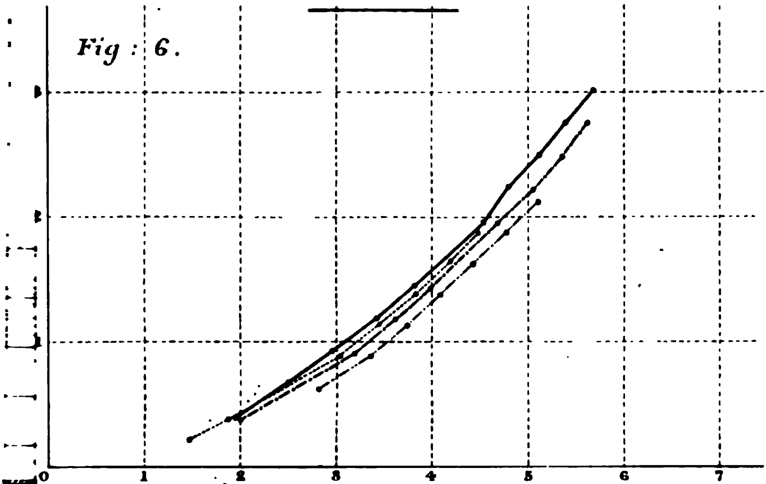
41° 2 Fahrenheit ————

53° 0 " ....

70° 4 " —·—·—·—

130° 5 " — — — —

Fig : 6.



Revolutions per Second.

Experiments with the same Disk in a Smooth and in a Rough Chamber.

BRIGHT BRASS 20" DISK.

In Smooth Chamber ....

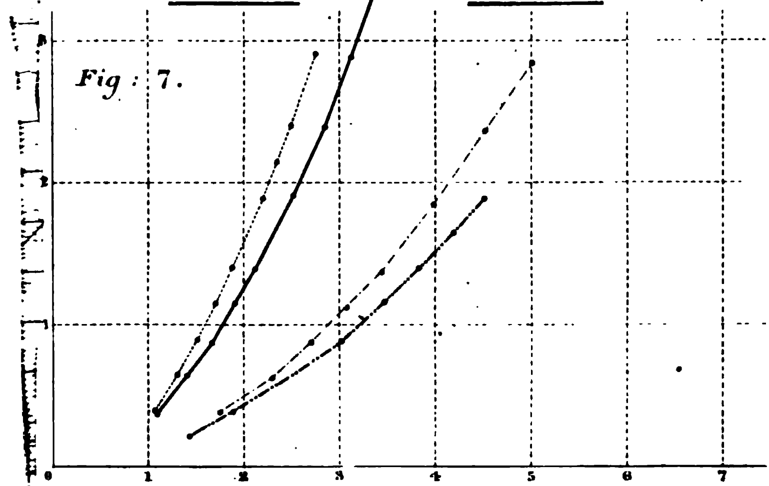
In Rough Sand Chamber —·—·—·—

ROUGH SAND 20" DISK.

In Smooth Chamber ————

In Rough Sand Chamber ....

Fig : 7.



Revolutions per Second.

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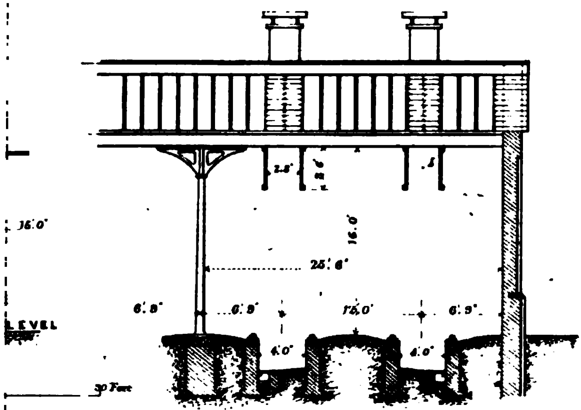

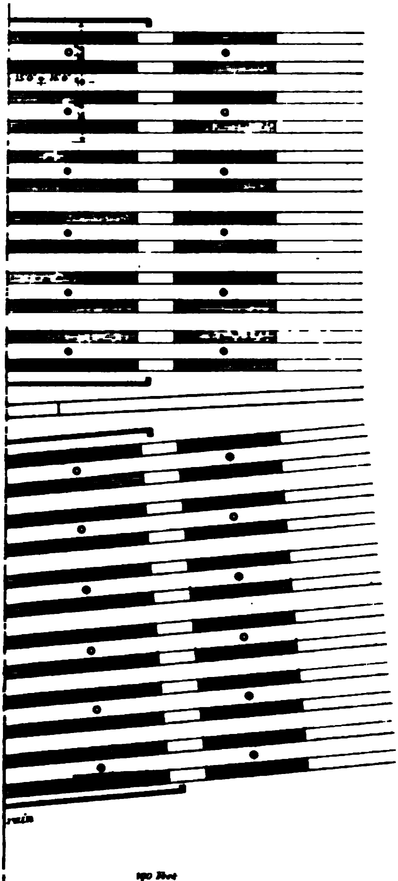

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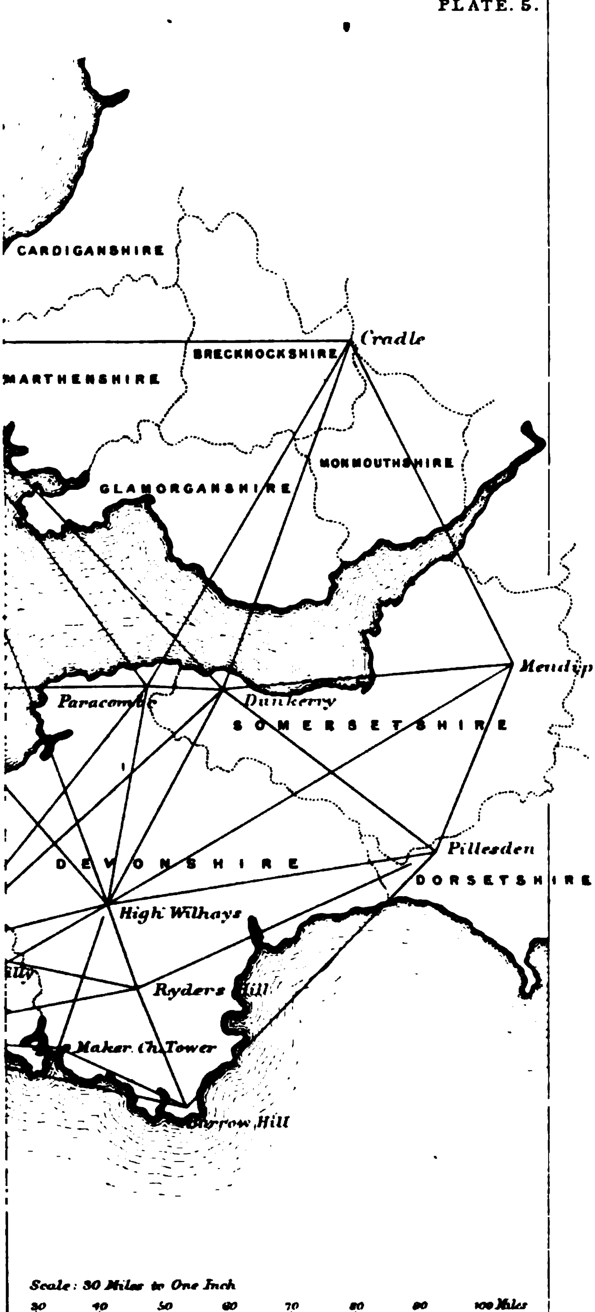
METRICAL SURVEYING.

RIMARY TRIANGULATION.

PLATE. 5.



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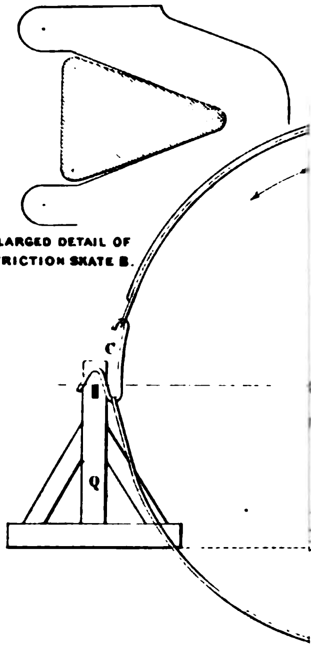

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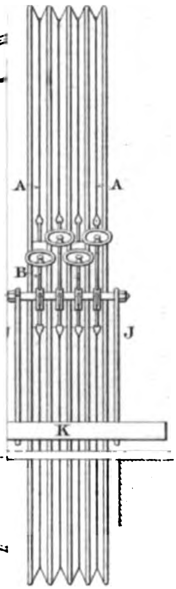

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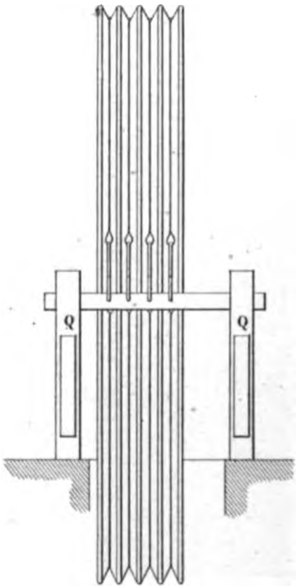

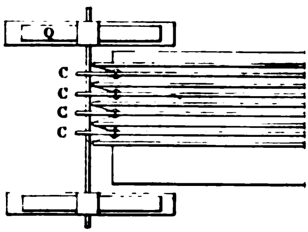

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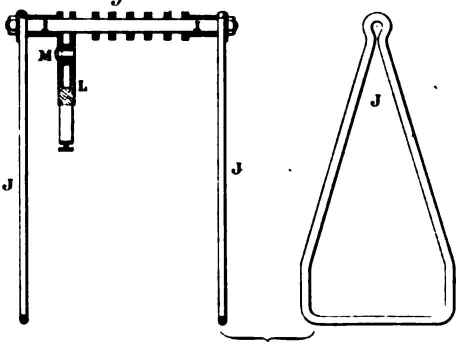

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